

Competitiveness and Productivity of the UK Design Engineering Sector

PACEC

Public & Corporate
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Competitiveness and Productivity of the UK Design Engineering Sector

A report for the UK Department
of Business, Enterprise and
Regulatory Reform

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"Design is not just what it looks like and feels like. Design is how it works."

– Steve Jobs, CEO and Founder of Apple, Inc.

"Leading innovations are the best form of copy protection for our products and a guarantor of the global success of BMW...."

– Professor Burkhard Goschel, BMW Board Member

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Acknowledgements

PACEC would like to extend their gratitude to the many people who contributed to this project. First and foremost, we would like to thank all those companies that participated in the case study interviews. These interviews provided the basis for much of the study and allowed for an in-depth study of the design engineering sector. We would also like to thank all those who replied to the survey of firms which allowed for a systematic comparison of firms.

In addition to the participating companies, the project benefited enormously from the advice and knowledge of industry experts. Our greatest debts of thanks go to Anthony Smith, Director of MediaTechnical, who among other things, provided a crucial analysis on the situation in India and China; Dr. Tim Scragg, formerly of the DTI Electronics Unit, provided continual guidance on the electronics industry; David Kynaston; John Moor, Director of Marketing at the National Microelectronics Institute, whose discussions on the microelectronics industry were invaluable; and the Society of Motor Manufacturers and Traders Design Engineering Group. In addition, Dr. Chris McArdle provided extremely useful insights into the workings of the electronics sector along with a copy of his highly informative Ph.D.

We would like to thank those who made the fact-finding trip to Silicon Valley, Detroit and San Antonio in the United States possible. Particular thanks go to Adam Fletcher of the Fabless Semiconductor Association and to Michael Ladika, Business Development Manager at Southwest Research who organised a full day of interviews, information sessions and site-tours for us at their company headquarters in San Antonio, Texas. Bruce Belzowski of University of Michigan Transportation Research Institute (UMTRI) was also very generous in meeting with us and providing highly informative discussions on the US automotive industry.

We would like to thank Paul Crawford, of the Department for Business, Enterprise and Regulatory Reform (formerly the Department of Trade and Industry) for being a highly knowledgeable client and for providing very stimulating and insightful discussions throughout the duration of the project. We would also like to thank all those in SPA and the wider department who have helped on the project either through providing advice, contacts or editing. Finally we would like to thank the Steering Group for their help and support throughout the project.

Executive Summary

X1 Introduction

- X1.1 The independent design engineering (IDE) sector is an important part of business services, a diverse sector engaged in providing services primarily to other businesses and which in the past been one of the most dynamic parts of the UK economy¹. It has doubled its share of UK GDP from 7% to 14% in the last two decades. The independent design engineering (IDE) sector is an important component of business services, and one which supports innovation in a wide range of customer sectors. Design is at the heart of all modern products and services.
- X1.2 The current globalisation wave has led to a substantial increase in the intensity of competition, putting pressure on manufacturers to specialise in activities where they are most competitive. In the electronics sector this has led to widespread outsourcing and offshoring of design as well as manufacturing. The same trend is evident in the automotive sector, except that the outsourcing of design was never as extensive.
- X1.3 The UK IDE sector has a competitive advantage in its specific niches, tends to be high value added, is innovation and export intensive, and plays a critical role in OEM outsourcing and offshoring programmes.

X2 Aims and Objectives

- X2.1 The overall aim of this study was to investigate the factors underpinning the competitiveness and performance of the UK's IDE sector. The study investigates two important IDE sectors, those serving the automotive and electronics industries. With respect to the latter, the focus is on the design of semiconductors. It is estimated that these two sectors generated revenues of about £1.6 billion in 2004. This study identifies the national and global innovation systems within which each sector operates, and attempts to answers the following key research questions:

- 1 How has the performance of the UK IDE sector changed through time and how does it compare to other overseas IDE sectors?
- 2 What is driving the market for the design engineering sector?
- 3 What are the key sources of competitive advantage in the IDE sector? What are the main sources of knowledge for the sector?
- 4 How have companies in the UK IDE sector adapted their capabilities to changing market conditions?
- 5 What business models have emerged to secure competitive advantage and gain market share in the IDE sector?
- 6 To what extent is the UK IDE sector globalising and what are the benefits to firms in the sector? Is a global presence a precondition for success?
- 7 What are the prospects for the sector? What are the main constraints on growth?

¹ DTI (2007) "Business Services and Globalisation", Economics Paper No. 19

X3 Key results

1. How has the performance of the UK IDE sector changed through time and how does it compare to other overseas IDE sectors?

Productivity has increased most rapidly in the fabless sector and currently compares favourably with that in the US. The UK dominates the global chipless sector and its productivity exceeds both the US and European sectors. The electronics contract design house sub-sector and the automotive IDE sector have shown limited productivity growth over the period.

X3.1 The productivity gains of the electronics design sub-sectors have largely been due to a small number of highly successful companies. Well known UK examples include Cambridge Silicon Radio in wireless communications, Wolfson Microelectronics in portable audio, ARM in semiconductor intellectual property, TTPCom in mobile telephony intellectual property, Cambridge Consultants in technology consultancy and Ricardo in automotive technology consultancy. Each of these commands a significant share of their sub-sector's revenues and is a global leader in their market niche. They typically rank at or near the top of their respective sectors in terms of performance (based on market shares, productivity and profitability).

X3.2 In addition to these global market leaders, a number of firms in the chipless and fabless sub-sectors are emerging as potential market leaders.

2. What is driving the market for the design engineering sector?

The long term trend to outsource design is very advanced in the electronics industry, but much less so in automotive. In contrast to electronics Original Equipment Manufacturers (OEMs) who focus on product development and brand management but outsource much of design, automotive OEMs consider design engineering a core capability. Cost-cutting programmes at Ford and GM have reduced the outsourcing of design.

X3.3 Product development tends to be kept in-house in most industries because it is fundamental to developing and maintaining competitive advantage, although some aspects of product development are outsourced to specialist IDE companies in the auto industry.

X3.4 The trend to outsource design engineering is very advanced in the electronics sector, driven by intense pressure to specialise by activity (e.g. product development, design, manufacturing, branding, marketing) and limited potential to exploit economies of scale in design. This has led to the development of a specialist electronics IDE sector, offering unique problem solving capabilities.

X3.5 The trend to outsource design engineering is not as advanced in the auto industry, although this is also a highly competitive industry with a long tradition of outsourcing the manufacture (and design) of components. Automotive OEMs currently consider most design engineering to be a core capability on which their competitive advantage

depends, but electronics OEMs do not. One explanation is that there is currently a big difference between the returns from product development and design in the two industries. The automotive industry rarely sees the colossal returns from product development seen in the electronics industry. The development of new cars with radically different functionality is uncommon, so that incremental design improvement is relatively more important. A second reason is that the potential market for independent design engineering is limited by perceived risks, in particular to intellectual property. The much longer product development and design cycle of a car means that the risk of IP leakage is greater.

- X3.6 Automotive OEM's design engineering strategies have changed markedly over time, and long term changes in technology and consumer preferences may lead them to change again. For example, engine design has tended to be kept in-house, but the increased importance to consumers of electronic over mechanically-based functionality may ultimately lead to the outsourcing of engine design as well.
- X3.7 UK auto design companies have been much more vulnerable to changes in customer outsourcing strategies because they have been more dependent on a few large customers, who have by and large maintained in-house design capabilities.
- X3.8 Technological progress has increased the potential for outsourcing and offshoring by reducing complex tasks to simpler modules. At the same time, this can lead to increased complexity in specific areas in the short term, such as interface design.
- X3.9 Ultimately the extent to which design is outsourced depends on the customer's overall strategy. A major 1999-2004 MIT study found that there was currently no dominant outsourcing strategy; for example, in the electronics industry Dell outsources all design, while Sony retains much of its design and manufacturing capability in-house (although this may be changing). In the automotive industry, Ford UK has brought back in-house design it used to outsource while using the independent sector primarily for capacity and piece work. German OEMs continue to outsource entire design modules to the independent design engineering sector.

3. What are the key sources of competitive advantage in the IDE sector?

Sources of competitive advantage are similar between the automotive and electronics IDE sectors. Core competitive advantages are the quality and breadth of capabilities and products, speed of service, flexibility, agility and reputation. The ability to collaborate effectively is increasingly important, particularly in the electronics sector, as the complexity of design increases. In the automotive sector the ability to enter new markets domestically and overseas is more important.

- X3.10 Offering the complete range of capabilities over an entire project (module or system) in general allows IDE firms to capture a greater portion of the value of design. Some automotive OEMs have reduced design costs by outsourcing piece work to the independent design engineering sector while keeping more complex design activities

in-house, whereas in electronics the complexity of the design task does not always permit a 'full service' strategy.

- X3.11 One of the key services offered by design companies to automotive OEMs is the reduction of time taken in the design process and hence time to market. These savings result from their relative 'nimbleness' and skills in design process innovation. Process innovation doesn't appear to be as important in electronics design, where innovation isn't so incremental, and products are more varied.
- X3.12 UK IDE firms, particularly in the electronics sector consider themselves more flexible and agile than overseas competitors. Agile IDEs have an important advantage when designing for the consumer and other electronics goods markets, where time-to-market is critical to success. Agility is increasingly important in the auto industry, because markets are moving faster while new products still take years to develop. Flexibility and agility is also vital for those design companies looking for an entry into rapidly expanding Far Eastern and other markets.
- X3.13 As the complexity of design and interfaces has increased, communication and co-operation between design partners has become more important, particularly in electronics, and the ability to collaborate effectively has become a competitive advantage.
- X3.14 Having a geographical presence near different partners in the system can therefore be important. In electronics design the need for close collaboration increases with the complexity of the task. In automotive design, OEMs consider proximity to be quite important. Both UK automotive and electronics IDE companies are less convinced of the need for design and production to be co-located. An exception is OEM customers from developing countries, who often have a larger gap in technological know-how and therefore greater need for reassurance.
- X3.15 Offshoring is often seen as a threat to UK industry, but the reality is not simple. IDE companies themselves are outsourcing and offshoring to access complementary skills and lower cost resources, and gain access to emerging markets in India and China. In the automotive sector, OEMs demand that IDE companies seek lower cost resources offshore. However, cost savings are sometimes not as great as expected because the quality and breadth of design resources in the Far East are not yet comparable, although these are developing rapidly.

4. What are the main sources of knowledge for the sector?

The UK design engineering sector benefits from external sources of knowledge primarily through working with customers. Universities play only a minor direct role as an external source of knowledge.

- X3.16 Close collaboration with customers facilitates knowledge flows to the IDE firm, particularly when customers retain a strong in-house R&D capability.

- X3.17 By contrast, universities are not major sources of knowledge, and only the largest companies in each sub-sector have significant formal relationships. However, most companies benefit indirectly through personal relationships, following academic research and attending conferences.

5. How have companies in the UK IDE sector adapted their capabilities to changing market conditions?

In response to difficult trading conditions in the automotive customer base, many IDE companies are diversifying into other sectors such as aerospace, and developing links with overseas customers and resources. Larger IDE companies are broadening their capabilities in critical areas such as electronics through strategic acquisitions.

- X3.18 In response to an expansion of their customer base, some electronics IDE companies have targeted their niche technological capabilities at niche end-user markets (e.g. fabless companies such as CSR and Wolfson Microelectronics and small specialised contract design houses), while some have targeted broad end-user markets (e.g. chipless companies such as ARM and large integrated contract design houses such as Cambridge Consultants).

6. What business models have emerged to secure competitive advantage and gain market share in the IDE sector?

Multiple business models exist in the both the automotive and electronics IDE sectors for securing competitive advantage and gaining market share.

- X3.19 The electronics IDE sector is characterised by three key business models: chipless, fabless and contract design houses, with examples of successful and profitable companies in each business model. Different facets of the business model include: licensing of intellectual property (IP) versus the marketing and sale of chips; niche technology, niche end-customer markets versus niche technology, broad end-customer market strategies; and the provision of complete solutions to complete projects versus specialised capabilities on part projects.
- X3.20 Similarly, different automotive IDE companies successfully pursue quite different business models from the provision of a range of capabilities across multiple modules and systems, to the provision of a range of capabilities across one module or system, and the provision of specialised capabilities for a sub-module or sub-system. The former two business models are typical of the larger IDE companies.
- X3.21 IDE companies operate successfully in a wide range of product groups, for example wireless communications, portable audio, unconfigurable and configurable processors, and digital audio in the electronics IDE sector, and vehicle dynamics, and engine design, calibration and testing in the automotive IDE sector.
- X3.22 Most, if not all, IDEs share the goal of serving larger, established customers as high up the value chain as possible.

7. To what extent is the UK IDE sector globalising and what are the benefits to firms in the sector?

The UK sector serves the global design market not just through exports, but also offshore offices, cross-border collaborations, and alliances with foreign partners. IDE companies are maintaining competitiveness by accessing overseas resources such as specialised knowledge and low cost labour, and by creating new routes to market. The leading UK automotive design firms are seeking to expand their overseas presence while maintaining their UK presence.

8. Is a global presence a precondition for success?

A presence in critical overseas markets through exports and offshore operations is important for both the automotive and electronic IDE sectors. Growth potential in the UK customer base is limited, but significant in overseas markets.

9. What are the prospects for the sector?

The global fabless market has more than doubled in the past five years from £9.2 billion in 2000 to £20.7 billion in 2005. It is highly dynamic with many new opportunities. The nascent UK fabless sub-sector shows the greatest growth potential in terms of the size of the incumbents and overall number of firms.

The chipless sector is much smaller and less dynamic, with the global market generating £724 million in 2005. It appears able to sustain only a small number of very successful companies and is already dominated by the UK.

The electronics contract design house shows limited potential for future growth due to intensifying competition both from existing firms and from new types of firms (e.g. original design manufacturers and firms increasingly providing complete product solutions where previously they would only offer a particular module).

Automotive IDE is the most mature sector, with a potential global market of approximately £3 billion in 2005. Again it appears able to only sustain the larger firms, with smaller firms obliged to seek improved margins elsewhere.

- X3.23 The potential for the appearance of major new UK design companies varies by sub-sector. The financial difficulties of the UK customer base is a major constraint in the UK automotive IDE sector, although these have been relatively successful in diversifying into new domestic and overseas markets.
- X3.24 Major entry barriers exist in the chipless sub-sector, primarily due to the importance of reputation. The high costs of switching from one provider of semiconductor intellectual property to another suggest limited potential for new entry in this global sector.

- X3.25 Electronics contract design houses operate in an intensely competitive market. Nonetheless, new sources of competition are arising, particularly from contract design and manufacturing companies (ODMs). There are good opportunities for small specialised consultancies where low entry barriers permit access to market niches.
- X3.26 Greater growth potential exists in the fabless sub-sector. The pressure to product differentiate and innovate, supported by rapidly changing technologies means that there are always opportunities. These market niches are typically narrow, but very large, global and rapidly expanding. Successful companies are typically not the first to develop the technology, but rather the first to successfully exploit it.

10. What are the main constraints to growth in the sector?

The problem of retaining experienced labour emerged as a constraint on growth for many IDE companies, particularly in the automotive sector. In the electronics IDE sector, adequate start-up funding is crucial to success but difficult to obtain.

- X3.27 Following the downturn in the electronics industry and difficult conditions in the automotive industry, many experienced engineers left the industry altogether. Now that the industry is picking up, a number of IDE firms are finding it difficult to recruit experienced engineers.
- X3.28 Securing adequate financing for a new start-up, especially in the fabless sector, can decide whether an entrant succeeds or not. Our research showed that securing such funding can be difficult, even in the electronics sector where the returns can be spectacular. Part of the apparent difficulty can be attributed to sub-standard business plans being submitted, which suggests that the necessary skills at compiling convincing, ambitious yet realistic business plans.

1 Introduction

1.1 Aims and objectives of the study

- 1.1.1 This is a study of the productivity and competitiveness of the UK independent design engineering (IDE) sector. The focus is on two sub-sectors; those which provide design engineering services to the automotive and the electronics industry. The report presents the findings for each sub-sector separately, although a common methodology and conceptual framework was used for the analysis. It should be noted that there is some overlap between these sub-sectors, in that the electronics design engineering sector indirectly provides services and components to the automotive industry.
- 1.1.2 The study was carried out against a background of restructuring in UK manufacturing, and the shift of manufacturing activity away from Europe and the United States towards the rapidly growing Asia-Pacific region and the Indian sub-continent. Many of the large, vertically-integrated companies which once dominated manufacturing have responded to increasing competition from lower cost economies by disintegrating operations that are no longer seen as core business. One common form of disintegration is the outsourcing of specific activities to specialist suppliers, sometimes offshore.²
- 1.1.3 The current wave of outsourcing began with internal services³ such as customer relations (call centres), cleaning, payroll, HR, accountancy, and logistics. It then spread to manufacturing operations, although not on the same scale. It now includes some 'higher value added' services such as research & development, and design engineering. The past three decades have witnessed a rapid growth in the market for independent design engineering services, particularly in the electronics sector, where the disintegration trend is most advanced.
- 1.1.4 The key aim of this study is to assess the achievements and competitiveness of the UK's IDE sector in addressing the domestic and international market for design engineering services, and to give some indication of future prospects.
- 1.1.5 Key research questions explored in the report include:
- 1 How has the performance of the UK IDE sector changed over time, and how does it compare to other overseas IDE sectors?
 - 2 What is driving the market for the design engineering sector?
 - 3 What are the key sources of competitive advantage in the UK IDE sector? What are the main sources of knowledge for the sector?
 - 4 How have companies in the UK IDE sector adapted their capabilities to changing market conditions?

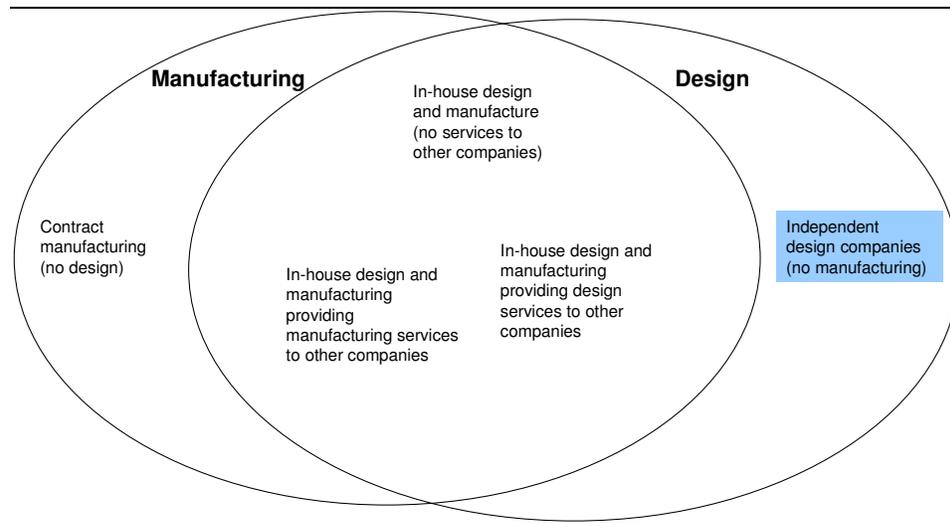
² A spin-off or de-merger is typically of an entire division or stand-alone company, whereas outsourcing tends to be of an activity which may take place across a number of divisions in a company. The aim of outsourcing is to buy rather than produce specific intermediate inputs, whereas the aim of a spin-out is to cease producing specific outputs.

³ Sometimes called Business Process Outsourcing (BPO).

- 5 What business models have emerged to secure competitive advantage and gain market share in the IDE sector?
 - 6 To what extent is the UK IDE sector globalising, and what are the benefits to firms in the sector? Is a global presence a precondition for success?
 - 7 What are the prospects for the sector? What are the main constraints on growth?
- 1.1.6 The study examines design engineering services supplied both in-house and by the *independent* design engineering sector, but the main focus is on the latter. The study also compares the UK sector with its counterparts in Europe and the United States.
- 1.1.7 Although the study is primarily concerned with understanding the factors influencing the productivity and competitiveness of the IDE sector, it also aims to assess the impact of the sector on the productivity and competitiveness of its customers, in order to understand the factors determining the growth of the market for the IDE sector.

1.2 Defining the sector and its activities

- 1.2.1 In delineating the independent design sector and selecting the companies to be included, the key criterion used is that the main activity of the company is design engineering. Thus, companies in which both design and manufacturing take place, but where the dominant activity is manufacturing, are excluded. Companies that design, but outsource the manufacturing of the 'product' to third parties, are included. The latter is particularly important in identifying companies providing design services to the electronics sector, where a semiconductor may be designed by a company that subsequently outsources its manufacture to another company. Such companies are included because their primary activity is design even though revenue arises from the sale of physical product or intellectual property. In some product markets, the independent design sector may be more involved in the design of components than the design of products using these components. For example, in developing an electronic product, semiconductor design often presents the core challenge, whereas in automotive design, although engine design is very important, independent design companies are involved in designing every aspect of the product. Figure 1.1 sets out the boundaries of the independent design engineering sector.

Figure 1.1 Boundaries of the independent design engineering sector

Source: PACEC analysis

- 1.2.2 Very little official data exists on the IDE sector. While firms typically assume Standard Industrial Classification (SIC) codes within SICs 72, 73 and 74, it is not uncommon for companies to assume the SIC code of their customers' sectors; for example, SIC 32.1. The Standard Occupational Classification (SOC) provides data on 'design and development engineers' (SOC code 2126), although this study considers that unsatisfactory for a number of reasons: (i) employees in the automotive and electronics IDE sector do not always identify themselves as 'design engineers' but rather as e.g. 'electronic' or 'mechanical' engineers; (ii) it is not possible to assign these employees to the specific IDE sector serving the automotive and electronics industries but only to the wider SIC codes (for example 74.2: architectural and engineering activities and related technical consultancy); and (iii) it is not possible to differentiate design engineers who work for the IDE sector from those who work for their customers.
- 1.2.3 Despite these caveats, it is nevertheless useful to analyse the SOC data. Table 1.1 shows the number of engineers, broken down by type (mechanical, electrical and electronic) in the three main sectors within which IDE firms are located (services sub-sectors⁴, electronics and automotive). In 2001, about 62,000 engineers were employed in these three sectors. This figure should be regarded as the upper limit of employment in the total IDE sector. This study found employment in 2004 in the specific IDE sectors of interest in this report to be approximately 15,000.

⁴ The services sub-sectors includes SICs in which the majority of DE companies are typically found. It was not possible to disaggregate the data further in automotive and electronics related employment.

Table 1.1 Employment of engineers in the automotive, electronics and IDE sectors

		All Engineering Professionals	All Mechanical, Electrical, Electronic and Design Engineers	Mechanical engineers	Electrical engineers	Electronics engineers	Design and development engineers
Services sub-sectors encompassing IDE-related services	72 Computer and related activities	12,707	9,376	6,760	190	435	1,991
	73 Research and development	6,271	3,972	2,408	119	431	1,014
	742 Architectural and engineering activities and related technical consultancy	54,606	26,996	13,221	1,624	794	11,357
	743 Technical testing and analysis	1,628	749	526	86	34	103
Services sub-sectors (electronics and automotive)		75,212	41,093	22,915	2,019	1,694	14,465
Electronics		23,065	13,156	3,750	821	2,119	6,466
Automotive		16,020	7,791	3,193	303	126	4,169
Total (IDE-related services, electronics and automotive)		114,297	62,040	29,858	3,143	3,939	25,100

Values are employees aged 16-74 in employment one week before the 2001 Census.

Service sub-sectors encompassing IDE-related services includes sub-sector SIC codes: 72, 73, 74.2 and 74.2. Further disaggregation according to whether they serve the electronics or automotive sectors was not possible.

Electronics includes sub-sector SIC codes: 30, 32, 33.1, 33.2, 33.3 and 33.4 (DTI definition, from DTI (2005))

Automotive includes sub-sector SIC codes: 34.1, 34.2 and 34.3 (DTI definition, from www.autoindustry.co.uk). Automotive sector should also include sub-sectors 25.11 (Tyres) and 31.61 (Automotive electrical equipment) but data could not be obtained at this level of detail.

Source: 2001 Census of Population (Table C0417 - Occupation (4 digit SOC) by Industry (3 digit SIC)), National Statistics

1.3 The conceptual framework

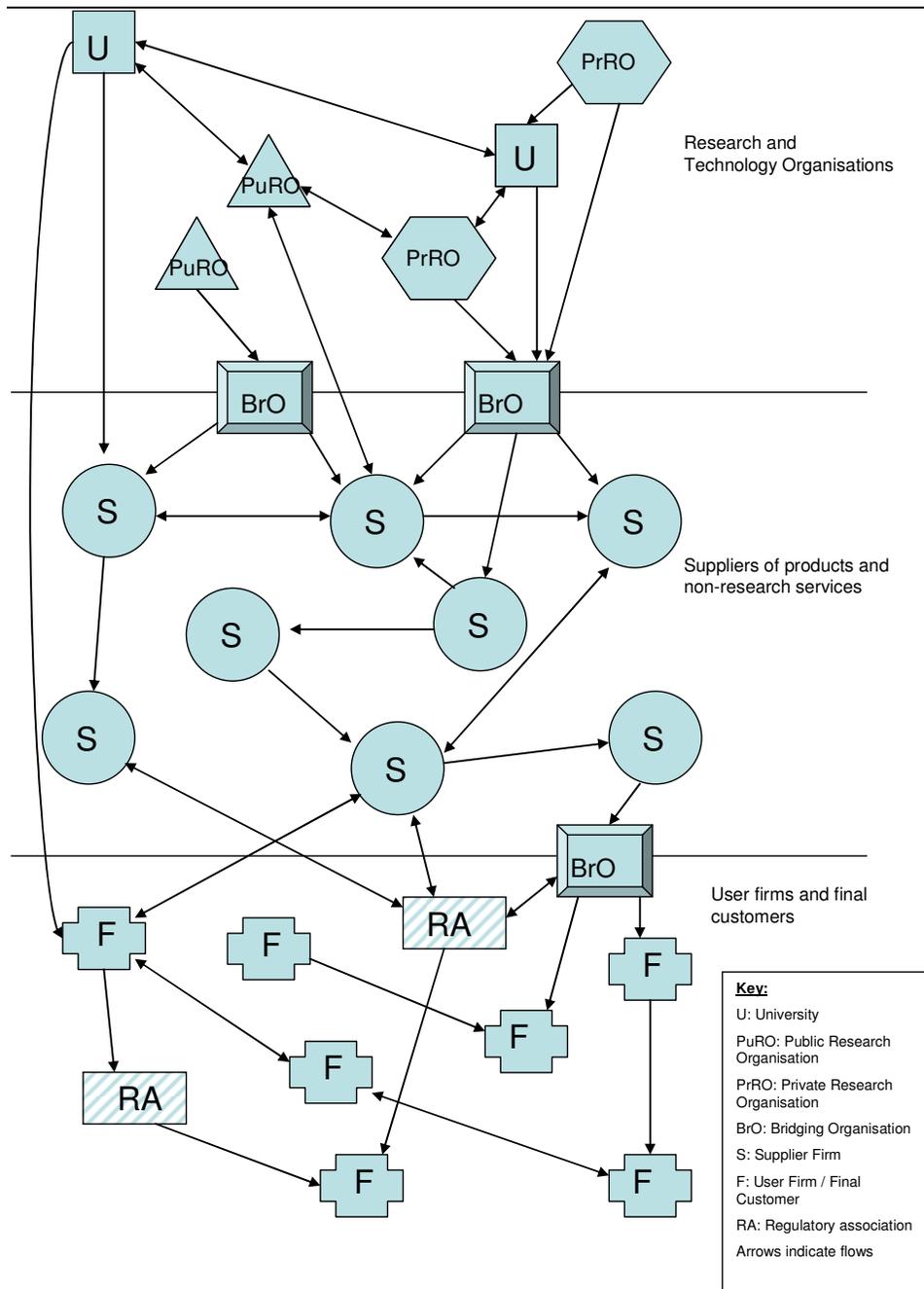
1.3.1 The IDE sector is primarily concerned with innovation, not only in respect of the services it provides and how it provides them, but also in support of the innovative activity of its customers. Partly for this reason, the empirical investigation of productivity and competitiveness in this study is set within a conceptual framework which focuses on the inter-relationships between firms in the innovation process. The importance of sources of scientific and technical knowledge external to a firm has long been recognised (Freeman, 1991), but recent decades have seen a marked acceleration in the growth of inter-firm relationships in knowledge transfer for innovation. These developments have stimulated new approaches to understanding the factors supporting innovation. These are based around the notion of 'sectoral innovation systems, and ideas of 'open innovation'⁵.

1.3.2 A central theme of these approaches is that innovation is increasingly spread across different firms and organisations in the innovation system. A key part of this is close collaboration between customers and providers of outsourced research and technology services (Coombes and Metcalfe, 1998). Innovation outsourcing allows firms to reduce costs, share risk, and shorten 'time-to-market'. This has been

⁵ See Anderson, Metcalfe and Tether (2000), Malerba (2004), and Chesbrough (2003).

facilitated by the modularisation of production and design processes which, in turn, enabled by the emergence of common technological and communication interfaces.

- 1.3.3 The key features of the sectoral innovation system framework are illustrated by Figure 1.2. This distinguishes three levels at which knowledge is generated and applied in the innovation process: research, suppliers and user firms and customers. There are horizontal and vertical patterns of interaction relating to different flows of knowledge and interdependencies (ranging from formal collaboration to informal interactions and scientific publishing). The number of agents in the system indicates the degree of vertical disintegration and division of labour.
- 1.3.4 The system contains firms which design and sell components and others which integrate different components, manufacture the final product and provide the link between the development of new products and market demand. The IDE sector sits at the central level in the supply chain network, providing design engineering services to other firms in the supply chain, and to user firms. It is closely linked with manufacturing activity and the in-house design capability in Original Equipment Manufacturers (OEMs) and supply chain firms. It may interact with universities or other research bodies in developing new or enhanced capabilities in support of the design of new products. Design companies are sometimes conceived as positioned on the boundary of the research community, acting as knowledge or technology brokers between academia and industry. But this is misleading because they are very much commercial organisations, for whom the supply chain is often a more important source of knowledge and technological advance.
- 1.3.5 Different organisational forms co-exist within the innovation system. At one extreme there are fully vertically-integrated companies which outsource relatively little. At the other, there are companies which outsource most design, production and distribution requirements to other firms in the supply network, focussing in some cases on 'brand management'. The size of the independent design engineering services sector depends largely on the outsourcing strategies of major customers, as well its innovation capabilities.
- 1.3.6 The spatial dimension is important to sectoral innovation systems. Companies' innovative activity is '*influenced by their home country's national system of innovation: the quality of basic research, workforce skills, systems of corporate governance, the degree of competitive rivalry and local inducement mechanisms*' (Pavitt and Patel, 1999). Innovation systems may overlap spatially; for example, both national and local innovation systems play a role in the innovation process where there is geographical clustering of firms. The electronics IDE sector tends to be geographically clustered in locations such as Silicon Valley in the US and Silicon Fen in Cambridge in the UK, while the automotive IDE sector is concentrated in the West Midlands in the UK and in Detroit in the US. Interdependencies between innovation systems also occur at the international level. For example, companies can access overseas innovation systems through cross border alliances, collaborative arrangements for R&D, and cross-border mergers and acquisitions.

Figure 1.2 A stylised sectoral innovations system

The above diagram represents a generic, stylised innovation system with the most likely linkages. It will be made specific to the electronics and automotive IDE sectors in the relevant chapters.

Source: Andersen, Metcalfe and Tether (2000)

1.3.7

An important aspect of the research was to identify and describe the strategic sectors and sub-sectors that constitute the innovation system within which the IDE sector is embedded. This empirical analysis will include the identification of the main agents in the system, their interactions and the institutional context shaping the behaviour of firms in the sector. Inevitably the boundaries of the automotive and electronics

innovation systems cannot be fixed precisely since they shift constantly in response to technological and economic changes.

- 1.3.8 The increasing use of electronics in vehicle manufacture demonstrates how different sectoral innovation systems may play a role in developing products for different markets. Innovation systems evolve in response to changes in technology, modes of interaction, regulation changes and markets.
- 1.3.9 In addressing issues of productivity and competitiveness of IDE firms and their customers the innovations systems framework highlights several factors of potential importance.
- 1.3.10 Firstly, innovation is placed centre stage as a key source of a firm's competitive advantage and productivity performance.
- 1.3.11 Secondly a variety of external sources of knowledge in the innovation process are important: the customer (OEM), other IDE firms, firms in the supplier network, and universities and research institutes. Innovation and the productivity improvements they generate are seen as the outcome of interaction and collaboration as well as improved process efficiency.
- 1.3.12 Thirdly, the different mechanisms for accessing knowledge need to be effectively managed. For customers of IDE firms, close interactive and iterative working may be required to ensure that new and improved components and technologies fit with existing systems and sub-systems. For IDE firms such interactive working with customers can enhance their capabilities and accumulated knowledge. This is particularly the case at the early stage of introducing an innovation or technological advance when managerial coordination (rather than the market) is often the most effective mechanism for coordinating relationships between provider and customer.

1.4 The research programme

- 1.4.1 The research programme for the study involved an integrated programme of tasks:
- A literature review relating to the IDE sector providing services to the electronics and automotive sectors. Government reports and academic research provided helpful insights and information, with specialist trade journals and magazines providing more detailed evidence
 - The establishment of a new company level database for profiling and describing the structure and performance of the IDE sector and for use in the econometric analysis of productivity. The database used was provided by ORBIS⁶ and consisted of standard company accounting information for the UK and other countries
 - Case studies and face-to-face interviews with key firms in the IDE sector and their customers in the electronics and automotive industries in the UK, US and EU, which were supplemented with a postal survey
 - An econometric analysis of the productivity performance of the UK IDE sector, using ORBIS firm level accounting data
 - A sector analysis of the UK IDE sector, focusing on:
 - structure and performance
 - markets and customers
 - innovation and technology development
 - collaborative relationships in the innovation system
 - market entry, competition and competitive advantage
 - An analysis of the significance of the independent design engineering sector for the productivity performance of customers.

1.5 Report overview

- 1.5.1 Following this introduction, the report is divided into two parts. Chapters 2 to 6 inclusive focus on the IDE sector providing services and products to the electronics industry, while Chapters 7 to 9 inclusive focus on the design engineering sector serving the automotive industry. This is for reasons of presentational clarity only. A common methodological approach is pursued as the sectors have sufficient structural similarity. Consequently, the reporting of each part follows a similar structure. More attention is given to electronics than auto design because this is a larger sector and the trends in the outsourcing of design are more advanced.
- 1.5.2 Chapter 2 provides an introduction to the specifics of the innovation system. It looks at how the electronics IDE sector fits into the wider innovation system and the role and links between the different players. It also presents an overview of recent developments in the innovation system.
- 1.5.3 Chapter 3 analyses the emergence of the market for design engineering services, analysing outsourcing and offshoring as mechanisms for improving competitiveness.

⁶ A brief description of the ORBIS database is provided in Appendix D

- 1.5.4 Chapter 4 focuses on the response of the UK IDE sector to the emerging market for design services. It analyses the scale and structure of the sector, and compares it to globally comparable sectors.
- 1.5.5 Chapter 5 investigates the evolution of the sector's performance in the UK, and compares it with IDE sectors in the US and Europe. Different measures of productivity and performance are developed, and econometric modelling is used to explore the factors determining cost and technical efficiency.
- 1.5.6 Chapter 6 focuses on the strategic responses of UK IDE companies in maintaining and strengthening competitive advantage.
- 1.5.7 Chapters 7-9 repeat this analysis for the automotive IDE sector.

2 The independent design engineering sector in the electronics innovation system

2.1 Introduction

2.1.1 Technological progress and intensified competition have led to the vertical disintegration of production and distribution systems in the electronics industry. At the same time, reductions in trade barriers and the emergence of rapidly growing new markets in Asia and other regions have shifted the locations of supply and demand.

2.1.2 The disintegration of the supply chain has led to the emergence of firms specialising in specific stages of the design, production, assembly and distribution of electronics components and products, increased collaboration between firms, and the co-ordination of activities across countries.

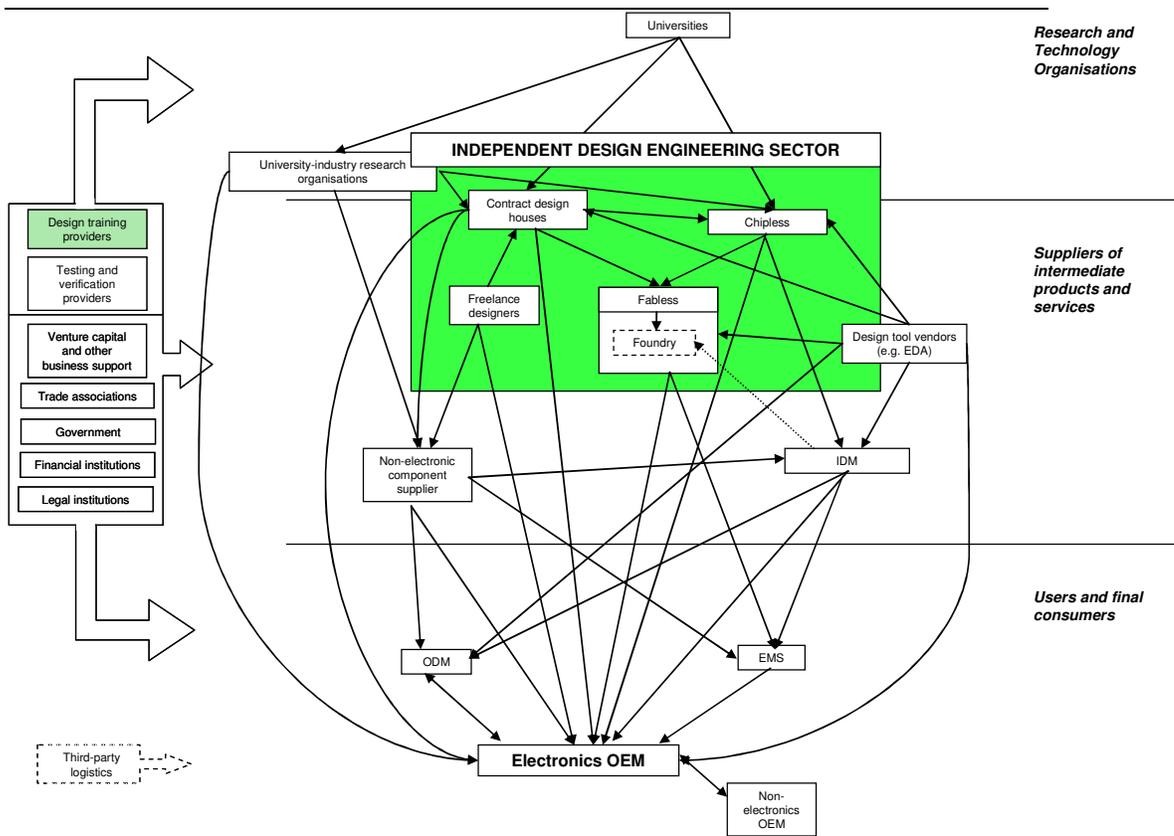
2.1.3 This chapter has two main aims. The first is to identify and describe the global electronics innovation system and the position of the independent design sector within it. A discussion of the structure and evolution of the innovation system supports the discussion of the development of the UK independent design sector in later chapters. The second is to describe the main design engineering activities, including system, integrated circuit, printed circuit boards and software design.

2.2 The electronics sectoral innovation system

Strategic sectors and sub-sectors

2.2.1 Within the electronics innovation system, the UK independent design sector collaborates, interacts and competes with independent design sectors and in-house design teams both in the UK and other countries. A simplified representation of the system is shown in Figure 2.1. Following Andersen, Metcalfe and Tether (2000), a distinction is made between horizontal and vertical interactions between different organisations. These interactions take a variety of forms; from market transactions to formal joint ventures and alliances, project-based collaborations and informal relationships.

Figure 2.1 The electronics innovation system



Source: PACEC analysis

2.2.2 Universities and research institutions provide an important but relatively small part of the research infrastructure of the electronics innovation system, particularly in semiconductor design. They partner OEMs and design companies in research and development (R&D), and provide skilled graduates and post graduates to refresh the skills and knowledge base.

- 2.2.3 Beyond the research base provided by universities and public research institutes, an international supply network of firms provides specialised intermediate services and products. These include Integrated Device Manufacturers (IDMs) such as STMicroelectronics, Infineon and Phillips Semiconductor. IDMs design, manufacture and sell semiconductors. They run their own foundries but sometimes outsource to cope with peak time pressures or take advantage of low cost producers.
- 2.2.4 The independent design sector forms part of the intermediate supply network of goods and services in the innovation system. The main sub-sectors of the independent design sector are the Chipless, Fabless, Contract Design Houses and Design Consultants. Companies in these sub-sectors are predominantly engaged in the design of semiconductors, other electronic products and their applications in final user products.
- 2.2.5 The UK has more Contract Design Houses than any other country in Europe (DTI, 2006). These are not owned by semiconductor or system OEMs, and provide design services for a range of customers. Their skills and capabilities range from semiconductor design to software and applications systems design across a range of electronics products. They typically offer both design and prototyping services, using their own design tools but working in collaboration with the customer. They may also act as a bridge for new technologies emerging from universities and research organisations. They may be small specialist or niche providers in particular aspects of design, or larger companies (such as Generics or PA Technology) offering a more comprehensive design capability.
- 2.2.6 Freelance design engineering consultants provide services to a range of customers, and are typically hired through specialist contract agencies. They may also, either individually or in project specific groups, secure design engineering consultancy assignments in specialist areas where they have experience and capability. While many freelance design engineers work for IDE companies on a sub-contract basis, it is also common for them to work directly for the customer base on specific aspects of projects.
- 2.2.7 Fabless companies design and market their own semiconductor devices, but outsource most or all of their manufacturing requirements to third party wafer foundries. The first Fabless semiconductor company, Chip & Technologies, was founded in 1984 and acquired by Intel in 1997. The UK has a presence in the global Fabless sector with companies such as Cambridge Silicon Radio and Wolfson Microelectronics. Most leading Fabless companies are located in the United States, although there are also major companies in Canada and Taiwan. Leading Fabless companies in the US include Qualcomm, with sales in 2003 exceeding \$2.5billion, Nvidia and Broadcom both with sales in excess of \$1.5billion.
- 2.2.8 Chipless companies do not manufacture semiconductors, but are engaged in the design and marketing of silicon intellectual property (SIP), or 'virtual components',

in the form of pre-designed, re-useable electronic circuit functions which can be integrated into a customer's integrated circuit (IC) design. They license 'blocks' of SIP to semiconductor manufacturers, who incorporate them into their own larger chip designs or use them to create system-on-chip (SoC) designs. These IP building blocks are known as 'cores' or design modules, and come in a variety of configurations. Some of these 'cores' can be modified by the customer (soft cores); others are 'hard cores' which cannot be modified.

- 2.2.9 The rapid growth in the market for SIP and reduced concerns about the loss of IP as a result of shortened product life cycles have been important factors in the growth of Chipless companies such as ARM, Rambus, MIPS and Arc International. The development of the Chipless sector and the growth in the market for the re-use and licensing of designs for integrated circuits has supported the increasing complexity of chips and a shift towards 'system on a chip' (SoC), in place of conventional integration on a printed circuit board. For example, there are now single-chip solutions for in-car navigation systems that incorporate the microprocessor for the GPS data, embedded memory and cellular phone. This development is eroding the boundary between the provision of SIPs and that of systems intellectual property. For example, TTPCom develop the embedded software for 3G mobile telephones, which includes both silicon and systems IP.
- 2.2.10 Electronic design automation (EDA) software suppliers/tool vendors, such as Cadence and Synopsis, and independent test and validation houses, are also closely involved in the design supply network. EDA software automates various stages of chip design, simulation and verification. EDA firms not only provide software but also provide libraries of pre-tested design 'cells' for use with their tools. These 'cells' are the basic building blocks from which chip designs are constructed. Some EDA software suppliers are now actively involved in designing and marketing silicon IP as well as providing design integration services for SoC products, using third party and customer modules. In 2005 Cadence had a market value of just over \$5 billion, and Synopsis, \$3 billion. EDAs supply products and services to manage the design of semiconductors to all companies engaged in chip design, including Original Design Manufacturers) ODMs, Contract Design Houses, Fabless and Chipless firms.
- 2.2.11 The bottom tier of Figure 2.1 shows the final producers and users of electronic products. This tier includes OEMs or systems firms, some of whom, for example Samsung and a number of Japanese corporations, retain a high degree of vertical integration. They manufacture and design electronic components and consumer electronic products, and supply and market their products under their brand name. However, a number of major electronics OEMs have outsourced much of the manufacturing of semiconductors, other electronics components and final products to contract manufacturers. Today, no major US or European electronics company operates as a fully-vertically integrated organisation. Faster growing OEMs, such as Cisco, Palm, Nokia and Apple tend to outsource much of their manufacturing activities. Electronic Manufacturing Service (EMS)

companies⁷ provide manufacturing and a wide range of other services, including design, assembly, testing, third party logistics and delivery; although procurement, supply chain management and inventory ownership often remain with the OEM. Examples of EMS/CMS companies are Flextronics, Solectron⁸ and Celestica.

2.2.12 The outsourcing of design by OEMs is clearly critical, as it determines the scale and dynamics of the market for the independent design sector. Some of the requirement for outsourced design is met by ODMs who offer a complete design and manufacturing service to OEMs specialising in the branding and marketing of electronics products. ODMs thus compete not only with EMS/CMS companies for the manufacturing of electronics products, but also with the independent design sector for outsourced design engineering services. Interestingly, ODMs are now emerging as direct competitors to OEMs with their own branded products (e.g. Hilmola et. al, 2005, pg. 3).

2.2.13 The institutional framework within which these firms operate is set by the interaction of a web of trade associations, government bodies, legal and financial institutions, regulations, technical standards and codes of behaviour.

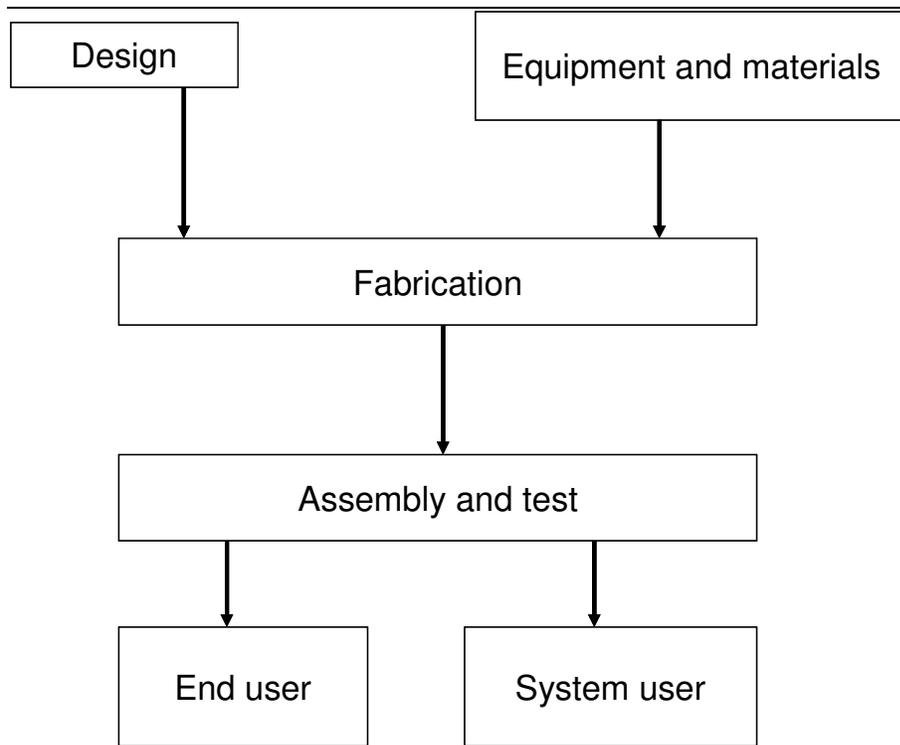
A dynamic system

2.2.14 The electronics innovation system is the outcome of continuous change and reconfiguration in response to processes of vertical disintegration and consolidation of its different sectors and sub-sectors. To understand this process we focus on the three primary activities in semiconductor production: design, fabrication and testing, and assembly, (see Figure 2.2). Design produces representations and simulates the performance of desired electronic circuits with advanced software tools. Fabrication involves the production of integrated circuits on silicon 'wafers', utilising complex manufacturing equipment, chemicals, gases and other materials. Assembly involves cutting the wafers into individual chips (or die), testing for defects, and packaging the chip in a protective housing, including connection pins to enable assembly into an electronic circuit.

⁷ Also known as Contract Manufacturing Services (CMS) companies.

⁸ These two firms have since merged.

Figure 2.2 Semiconductor industry value chain

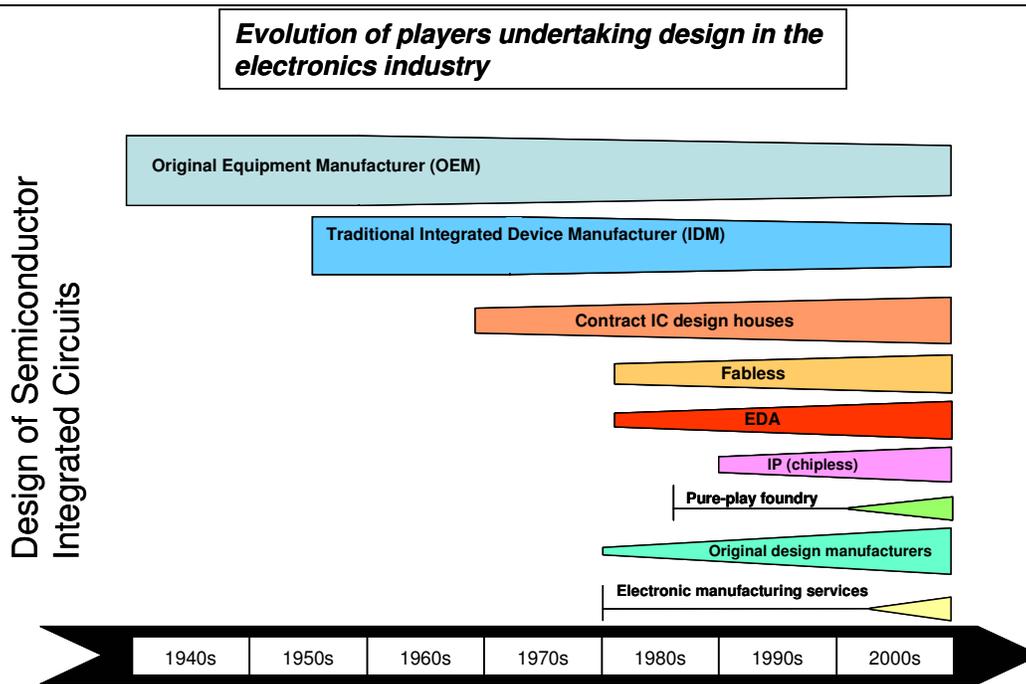


Source: Macher et al (2002)

- 2.2.15 In the early years of vertically-integrated companies, design was typically undertaken in-house by the large, integrated electronics producers (OEMs). The decoupling of design to IDMs began in the late 1950s, with a partial shift in the responsibility for designing integrated circuits and other components (see Figure 2.3). By the 1990s, increased foreign competition had resulted in many larger OEMs downsizing, divesting departments, being consolidated or sold (Future Horizons, 2006). Pure (“blue sky”) research increasingly became the domain of the universities and government agencies, and applied research was downsized through outsourcing. All these factors led to an increased number of senior managers and engineers with highly specialised skills and knowledge entering the labour market. Many joined or formed Contract Design Houses. At the same time, all but the largest OEMs looked increasingly to external sources of design to reduce costs.
- 2.2.16 So-called chipless companies such as Rambus, ARM and MIPS Technology emerged during the 1990s. This further increased the vertical specialisation of design, because these firms tended to specialise in specific product areas, such as mobile telecommunications.
- 2.2.17 The design of electronic systems followed a similar pattern of vertical disintegration to that of semiconductor design. In particular there was a shift from mass market standardised products, to Application Specific Integrated Circuit (ASIC). This meant that the economies of scale in manufacturing chips were no longer being achieved and many of the smaller players began to find ways to

decouple design from manufacturing. In the 1990s, the ASIC market was still dominated by large OEMs such as IBM, Lucent and Fujitsu, with strong systems integration capabilities; however, by 2002 companies such as Intel, Qualcomm, STMicroelectronics, Infineon and Phillips Semiconductors dominated the market (Dibiaggio, 2006)⁹.

Figure 2.3 Evolution of the sub-sectors undertaking semiconductor design



Sources: PACEC, Reed Electronics Movers and Shakers, National Microelectronics Institute (2004), Linden and Samoya (2003), Brown and Linden (2005), Macher et al. (2002), Ernst (2004)

- 2.2.18 The semiconductor fabrication process is very capital intensive, in contrast to the semiconductor design process. About 20% of annual revenues is spent on capital equipment, and 15% on R&D (EECA-ES (2005)). According to Moore's second law, costs for state of the art production process roughly double between two chip generations. Today, a modern fabrication facility costs over £1.5billion, and will need to be upgraded several times in its lifetime.
- 2.2.19 These high and increasing capital setup costs played an important role in the divestment of semiconductor fabrication by OEMs and the birth of Fabless business models in the 1980s. Only the largest OEMs were able to establish their own fabrication plants (fabs) and produce enough chips to take full advantage of economies of scale. Initially, Fabless companies relied on personal contacts within IDMs for access to fabrication capability and capacity; but the creation of independent 'foundries' (dedicated contract semiconductor

⁹ Based on an analysis by Dibiaggio (2006) of the top ten firms in the ASIC market in 1996, 1999 and 2002 according to ASIC revenue.

manufacturing facilities) gave Fabless companies access to wafer production technology on a par with the larger IDMs. US companies dominate this part of the independent design sector. In 2004, the largest Fabless company was Qualcomm, based in California with a turnover of \$3.2 billion.

- 2.2.20 The dedicated foundry model originated in Taiwan in the late 1980s, when the Taiwanese government brought together Taiwanese engineers with experience in the US to found the Taiwan Semiconductor Manufacturing Corporation (TSMC). In 2004 TSMC dominated the sector with a turnover of over \$7.6billion, about 46% of the total market (EE Times (2005)). Asian Foundries also provide manufacturing capacity for IDMs, who began outsourcing in the mid-1990s. The Fabless-Foundry business model also exists in Europe; Cambridge Silicon Radio is a notable example in the UK.

Regional distribution

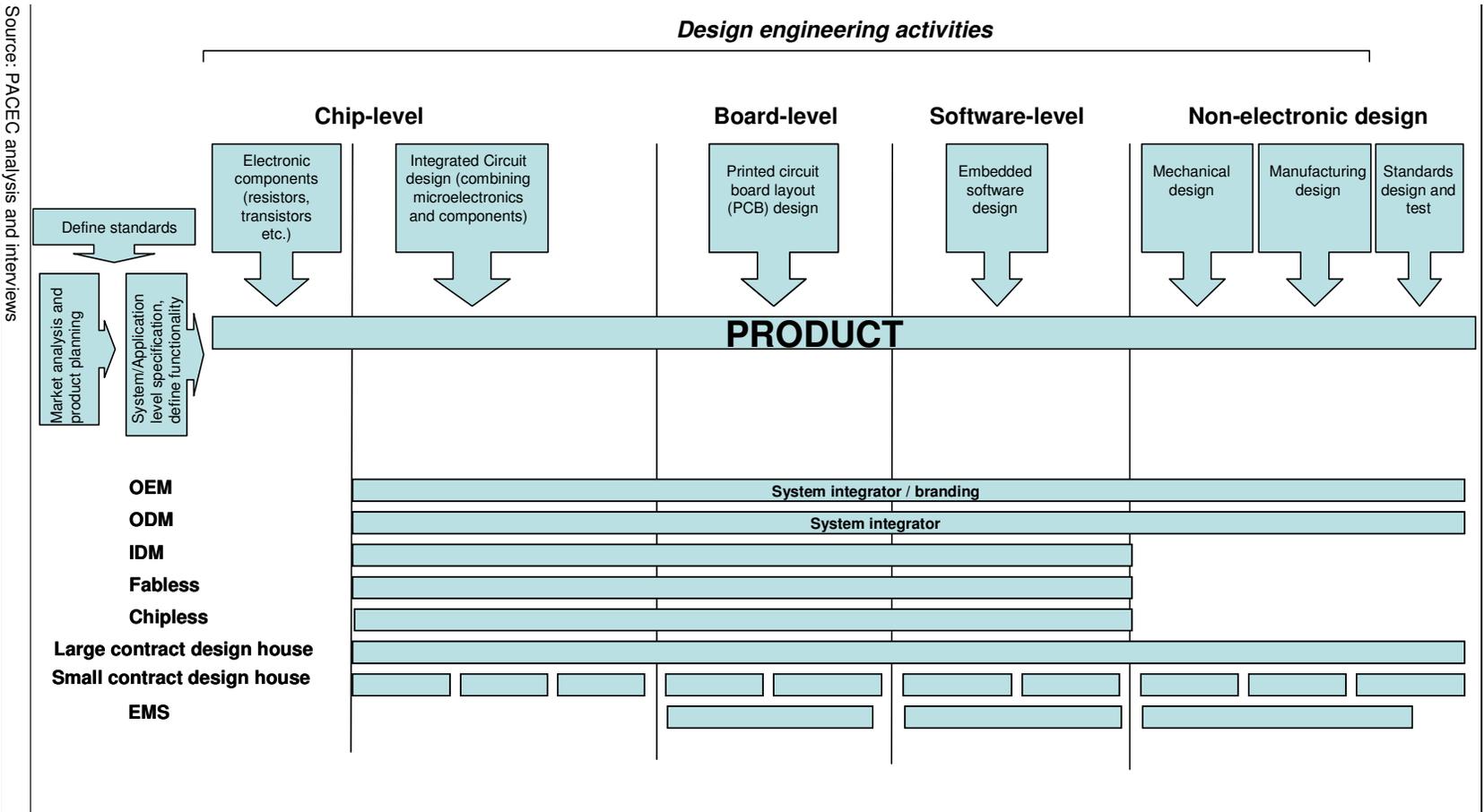
- 2.2.21 The regional specialisation of the electronics innovation system is a second key development in electronics design. In the past two decades, semiconductor manufacturing capacity has shifted from Europe, Japan and North America to the Asia-Pacific (Taiwan, South Korea and Singapore). OEMs in the US and Europe have relocated much of their electronics manufacturing activity to Asia-Pacific and China. At the same time, the markets for electronics products are growing most rapidly in Asia-Pacific, the Indian sub-continent and China.

2.3 Semiconductor and system design activities

- 2.3.1 The design process is highly skill intensive, requiring design engineers across a range of activities. Figure 2.4 distinguishes four broad types of design activity:
- Complete system design, including specification and hardware and software integration
 - Chip design
 - Printed circuit board (PCB) design
 - Software design
- 2.3.2 Entire system design relates to the different functions required in the final product, and derives critically from an understanding of customers' needs and the response of providers seeking to innovate and differentiate their product or service in the market. It includes technical features as well as product styling.
- 2.3.3 Integrated circuits (IC) or 'chips' are miniaturised electronic components built into an electrical network, typically on a piece of silicon. The design of an integrated circuit or chip involves the creation of electronic components, such as transistors, resistors and capacitors, and their interconnection in a piece of semiconductor. Modern chips may contain millions of transistors. The complexity of the design process has led to the development of software for automated design. Design tasks include the conversion of user specification into a detailed chip specification, the identification of which logic gates to use, and connecting them together.
- 2.3.4 Most electronic products contain a Printed Circuit Board (PCB) on which individual electronic components are placed and interconnected. The design task aims to provide the optimum circuit layout of different electronic components, such as Integrated Circuits (ICs), capacitors, inductors, resistors and their interconnections, positioned on the PCB. PCB design complexity increases if the board is multilayered. PCB design is typically carried out by small teams who see the whole design through to completion. In System-on-Chip (SoC) design, many functions are combined on one IC instead of being distributed on a conventional printed circuit board. A SoC may incorporate a microprocessor, memory, signal processors and input output controllers.
- 2.3.5 Embedded software design provides the intelligence that ensures the functionality of the hardware. This design task takes place at different levels of integration, for example at the chip level, at the level of the PCB, and at the level of the overall system, possibly involving other PCBs and enclosures. Software design has become increasingly challenging as the complexity of chip and systems design has increased. Within each of these broad design stages more finely disaggregated design activities are specified. Those that are typically outsourced are discussed in Chapter 3.

2.3.6 The bottom of Figure 2.4 shows the different strategic groups in the system in relation to the design activities they may undertake. At one extreme are the OEMs with the potential to undertake all design activities in-house. At the other extreme are niche players focusing on one or more of the disaggregated design activities identified. The extent to which each design activity presents a market opportunity for the UK independent design sector and other players in the innovation system turns critically on the design outsourcing strategies of OEMs, ODMs and other organisations.

Figure 2.4 Design activities for the development of electronic products



2.3.7 Design engineering is a substantial input to major new electronics products. Chip design, in particular, is very skill intensive and is becoming more so as the complexity increases. For example, several hundred engineers worked on Intel's Pentium 4 chip for the full length of the five year project. Table 2.1 shows changes in the input of engineering hours to design 1 million logic transistors since the mid-1990s, with process technology at the 350 nanometer linewidth to 130nm linewidth in 2003. The project is a standard digital logic design (memory, analog chips etc would have a different input mix of engineering hours).

2.3.8 The growing importance of software inputs is notable. The amount of software required increases with both the size and complexity of the chip, and the greater extent with which the chip must integrate with multiple other systems. A typical stand-alone chip in 1995 required just 100,000 lines of code. In 2002, this had reached a million (Brown and Linden, 2005). Software is becoming increasingly important to companies as the value of new products shifts from hardware (e.g. chips) to the code that brings it to life. This is most apparent in consumer and industrial products where software, rather than hardware is becoming the key differentiator. For example, in the automotive sector, a McKinsey & Co. study claimed that embedded software now drives most of the industry's innovations and accounts for an increasing part of a car's value. Therefore, software, whether in-house or outsourced, is a major source of semiconductor firms' competitive advantage.

2.3.9 Specification has also increased substantially, but accounted for only 7.8% of engineer input hours. Increases in logic and physical design engineering hours inputs are much less, primarily owing to greater automation of chip design.

Table 2.1 Engineer hours to design 1 million logic transistors

	350nm	250nm	180nm	130nm	Change from 350 to 130nm (%)
Specification	23.0	29.8	91.4	271.6	1081
Logic design	714.2	738.4	756.4	837.7	17
Physical design	311.0	357.2	391.7	473.5	52
Validation	103.7	127.6	164.5	197.4	90
Software	378.4	672.4	985.7	1798.3	375
Total	1530.3	1925.4	2389.7	3578.5	134

Source: Brown and Linden (2005)

3 Creating a market for design

3.1 Introduction

- 3.1.1 This chapter analyses the nature and dynamics of the market for the UK's independent design sector.
- 3.1.2 The independent electronics design sector emerged from strategic decisions by large integrated US and European electronics OEMs to outsource some or all of their requirements for design, primarily to lower costs. The outsourcing of chip manufacturing and assembly has long been a feature of the electronics industry, but in recent decades an increasing number of firms have outsourced work in printed circuit board design, chip design, software development and complete system design. These developments reflect a more general trend towards 'open innovation' in which companies collaborate with global networks of partners (suppliers, customers, intermediaries) in bringing new products to market. OEMs use independent design houses who themselves may subcontract with one another, depending on areas of expertise.
- 3.1.3 Market developments are difficult to judge, not least because different OEMs are adopting different outsourcing strategies. Dell for example, undertakes little in-house design for notebook PCs and other electronics products, in sharp contrast to Sony (Berger, 2005, pgs153-160). Sony conducts much of its design and manufacturing in-house (although it does outsource some of its low-end laptops to third party manufacturers). However, Sony is increasingly collaborating in areas such as processor design (e.g. with IBM and Toshiba). Other companies such as Motorola maintain in-house R&D capability for selected products, using the latest technologies, but buy in complete designs for less expensive mobile phones.
- 3.1.4 OEMs outsource design to ODMs, who both manufacture and design new products, as well as to the independent design sector. Many semiconductor ODMs are based in Taiwan and are major players in this open innovation system. Driven in large part by competitive pressures and facilitated by technological and market developments, today's global electronics innovation system is characterised by a complex web of corporate interactions, providing diverse opportunities for the UK independent design sector.
- 3.1.5 OEMs and other companies in the electronics innovation system are also seeking to offshore different stages in the production process. Some are both offshoring and outsourcing different stages of the production process. As with outsourcing, the offshoring of design has tended to lag behind that of manufacturing and assembly. This offshoring is not only through the traditional route of overseas investment, but also via international collaborative relationships, alliances and joint ventures.
- 3.1.6 The evidence presented in this chapter suggests that emerging market trends and competitive pressures are accelerating the outsourcing and offshoring of electronic

design. Although the majority of outsourced design remains in the home country, design is increasingly migrating towards both low cost destinations such as India, China and Eastern Europe, and towards those areas with the greatest expertise, regardless of its cost-base. These trends are changing the competitive landscape for the UK independent design sector albeit slowly.

- 3.1.7 This chapter analyses outsourcing and offshoring trends in semiconductor and systems design as the outcome of strategic shifts in the organisation of production in response to intensifying global competition. These trends determine the scale, composition, and location of semiconductor and systems design market opportunities for the UK independent sector. Different factors underpinning these trends are analysed, including the role of modularisation, transaction costs, standards and technological advances. Although the focus here is on innovation and design, the future outsourcing and offshoring of other components in the production chain could also affect the design sector.

3.2 The emergence of markets for the independent design sector

3.2.1 The past twenty five years have witnessed a substantial shift towards the offshoring and outsourcing of the different stages in the production of semiconductors and system applications. Offshoring involves the movement of some or all of a firm's semiconductor and component production stages (design, manufacturing and assembly) to locations outside the home country. Outsourcing involves different stages of the production process being undertaken under contract by other firms and may take place in the home country or offshore. These two phenomena have been important features of the electronics industry for several decades, leading to a major restructuring and global relocation of the industry and its supply chain.

Offshoring and outsourcing of fabrication and assembly

3.2.2 In the early years of the semiconductor and electronic component industry, outsourcing and offshoring were primarily limited to the fabrication and assembly stages of the production process. Figure 3.1 reveals a gradual increase in vertical specialisation and globalisation of these stages of the production process since the 1950s and 1960s. Assembly, with its relatively high employment of less skilled labour, encouraged large US semiconductor firms to offshore in search of lower labour costs; although initially OEMs such as IBM and AT&T retained their assembly in the US, and relied on increased automation to reduce costs. Over time, intensified competition led to the domination of assembly by Asian providers, as in-house offshoring was gradually supplanted by offshore outsourcing (Brown and Linden, 2005).

3.2.3 The most important developments in the fabrication of semiconductors has been the emergence of independent 'foundries' which appeared in the 1980s and the shift of fabrication to the Asia Pacific (excluding Japan) since the mid-1980s. Foundries mainly manufacture chips to the design of other companies, notably fabless firms in the independent design sector but also other players¹⁰. While they began as "pure-play", (i.e. only manufacturing), few now are, and often now have some design capability. The fabless sector is dominated by US firms and their outsourcing and offshoring of chip manufacturing is mainly to Asia (Taiwan, Singapore, China and South Korea). In addition, both large and small integrated firms offshore and outsource to foundries in the Asia-Pacific. In part, this trend reflects the high risks and huge cost of building and maintaining new fab capacity. Brown and Linden (2005) estimated that between 20% and 25% of the value of semiconductor fabrication is outsourced and offshored and that about a third of US fab capacity is located outside the US.

¹⁰ OEMs and IDMs began using Asian foundries in the mid-1990s.

Source: PACEC, Brown and Linden (2005), Linden and Samoya (2003.), Hilmola et al. (2004), Ernst (2000), Macher et al. (2002), NMI (2004)

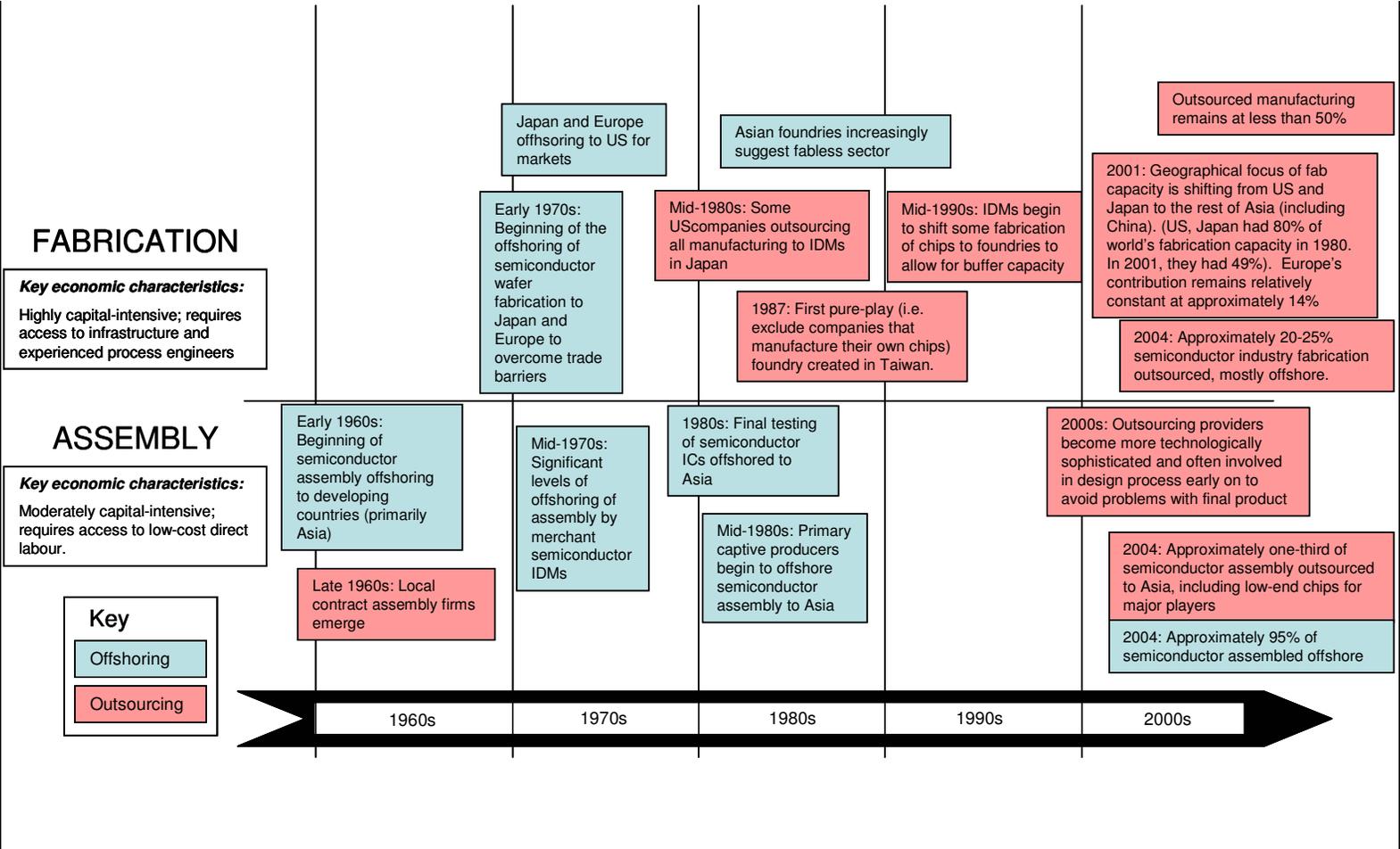


Figure 3.1 Evolution of offshoring and outsourcing in the fabrication and assembly of semiconductor systems

Offshoring and outsourcing of design

- 3.2.4 Unlike the fabrication and assembly of chips, there has been geographical clustering of chip design in most countries with a significant design capability, Silicon Valley being the outstanding example. System companies (OEMs) and IDMs have also tended to undertake much of their design in-house, rather than outsourcing it to specialised suppliers. Moreover, most outsourcing of design continues to go to suppliers located in the home country. These features of the design process are partly explained by the highly complex technology used in chip design, involving substantial verification, testing and experimentation, in which close collaboration and knowledge exchange between users and producers is important. A further incentive for operating in geographical clusters is that it affords easy access to the wide range of expertise/knowledge (e.g. design engineering skills, financial expertise, IPR management) required to take a chip from initial design to final use (Ernst, 2005).
- 3.2.5 At the same time, factors on both the demand and supply side of chip design are generating increased mobility of design internationally. Asia-Pacific (excluding Japan) is emerging as the primary destination for design offshoring because of lower labour costs and the perceived advantages of being close to large and rapidly expanding new markets. Government policy in Asia has been crucial in providing a business environment that is attractive to the global chip design community, leading to the formation of new clusters of semiconductor design, fabrication and assembly.
- 3.2.6 The mobility of chip design activity can be traced back over several decades, (Brown and Linden (2005)). In the 1960s and 1970s, in-house offshoring of semiconductor design was mainly by US companies to Western Europe and Japan. The 1980s saw the offshoring of design centres to Hong Kong, Taiwan and Singapore, with the aim of adapting ICs to local market needs. Texas Instruments was one of the first companies to establish a design centre in India, in 1985. The need for specialised skills, such as expertise in multimedia (UK) and telecoms (Sweden) encouraged US design investments in these countries, through the establishment of design centres, and acquisitions, such as Broadcom's takeover of Element 14, a UK Fabless company (Brown and Linden (2005)). However, offshoring for purposes of cost reduction has been, and remains very important, particularly to Asia-Pacific (ex Japan) and India.
- 3.2.7 At the same time, many Western European companies, such as Philips and Japanese companies such as Hitachi, also offshored some design and extended their global presence. Again, a combination of market development, access to engineering talent and cost reduction factors led Western European and Japanese companies to offshore to the US (Silicon Valley and other US design clusters), India, China and other Far Eastern countries.
- 3.2.8 The outsourcing of semiconductor and systems design also dates back to the 1950s, when a number of US OEMs began to meet some or all of their chip requirements from specialist semiconductor component/ integrated device manufacturers (IDMs) or so-called 'merchant' vendors, a practice which later spread to Europe. It was not until

the mid-1960s/1970s that Contract Design Houses began to provide design services to OEMs. In the late 1980s and 1990s design outsourcing gathered further momentum with the increasing importance of (ODMs), who provide both manufacturing and design capabilities. A major watershed in the evolution of design outsourcing and offshoring of both semiconductor and other electronic systems occurred in the 1980s, with the decoupling of design from fabrication and the emergence of the fabless and chipless IP models. This provided major new market opportunities for the independent design sector, initially in the US but later in Western Europe, including the UK. These trends are summarised in Figure 3.2.

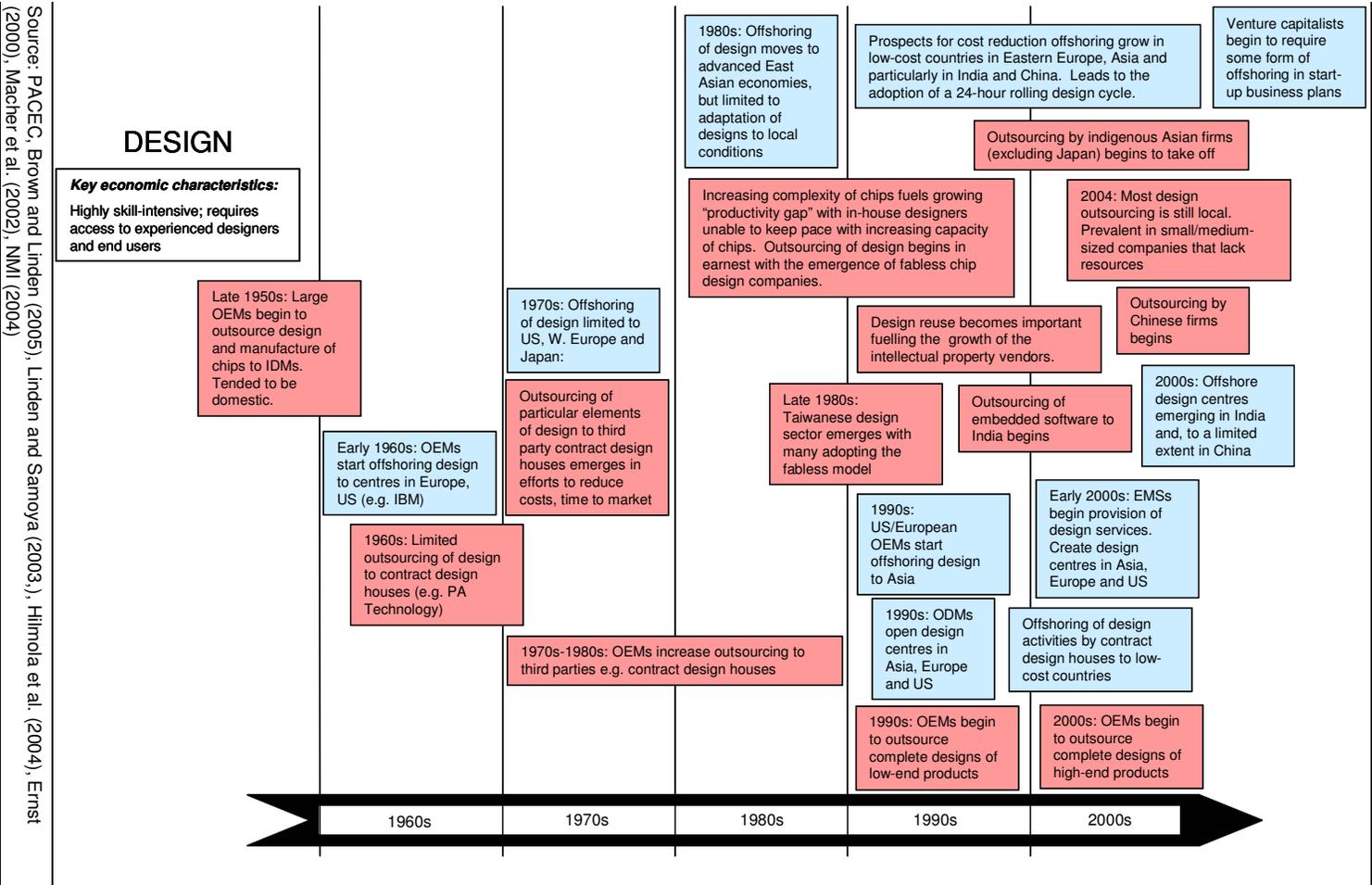


Figure 3.2 Evolution of offshoring and outsourcing of design activities in semiconductor systems

- 3.2.9 Our review of the evidence on offshoring and outsourcing of chip design suggests that it is becoming much more spatially mobile and more geographically dispersed. Taiwan, Korea, Malaysia, Singapore, China and India are emerging as key destinations for design, (Ernst, 2004). In addition, China and India are looking to develop their capabilities in designing integrated systems. While these regions present a new and growing source of competition, they also provide market opportunities for the independent design sector. In the past decade, increasing design costs and the spread of high-bandwidth infrastructure have encouraged US and Western European companies to source more and more of their design activities from low cost industrialising countries in Eastern Europe and Asia. In these countries, a combination of a supportive business environment (with tax rebates, an increasingly skilled and experienced workforce, easy access to foundries and a dense and specialised network of suppliers) and expanding market opportunities is encouraging major US and European OEMs and ODMs to expand and upgrade their design centres in Asia. Some companies are strategically locating their design operations offshore to permit a 24 hour design cycle. For example, by locating offices in, say China, the UK and Silicon Valley, with adequate codification and communication of design tasks, work can be passed from office to office around the globe to ensure that downtime in the 24-hour period is minimised.
- 3.2.10 Design capability in Asia (excluding Japan) is emerging as a major 'pull' factor for design offshoring and outsourcing. This began in the 1980s with PCB design for computers and other electronics products, and broadened substantially in the late 1980s/90s. The emergence of ODMs and Fabless companies in Taiwan significantly increased this design capability. Focussed on niche markets and supported by continuously improving EDA tools, Taiwanese companies have developed a highly competitive design sector. The hub of worldwide ODM manufacturing activity is still Taiwan, which manufactures two thirds of the world's notebook PCs¹¹, over 50% of world shipments of PDAs and two thirds of global LCD monitors. Mediatek and ALi have become important suppliers to Chinese makers of DVD players, and a number of Taiwanese firms are moving into consumer and communications systems design.
- 3.2.11 Developing rapid time-to-market, as well as local cost advantages and the capacity to access global capabilities have been critical to this success. Partnerships between companies in Hsinchu, Taiwan and in Silicon Valley, US, such as that between Sunplus Technology, Oak Technology and Silicon Image, are examples of countless collaborations (formal and informal) helping Taiwanese companies move up the design value chain. Taiwan's IC manufacturing expertise is also attracting design capability from overseas. Many of these partnerships are close, and in some cases long-term. For example, collaboration between some fabless companies and foundries has matured to the point where engineers from the fabless company work on site in the foundry.
- 3.2.12 By 2000, Taiwan was one of the most sophisticated global centres of specialised IC design and fabrication outside Silicon Valley; with 130 independent design

¹¹ Business Week, March 2005

companies, 100 assembly and test companies, 20 wafer manufacturers and 5 mask makers, all engaged in a complex and diverse web of local and cross-region supplier relationships (Saxenian, 2006). Further evidence of the emergence of Taiwan as a major global design concentration is provided by TSMC's investment in Global UniChipCorp (GUC), a specialised IDE service provider. The establishment of this 'design foundry' reflects the increased closeness required of design and fabrication technology, and the competitive strength of Taiwan in fabrication.

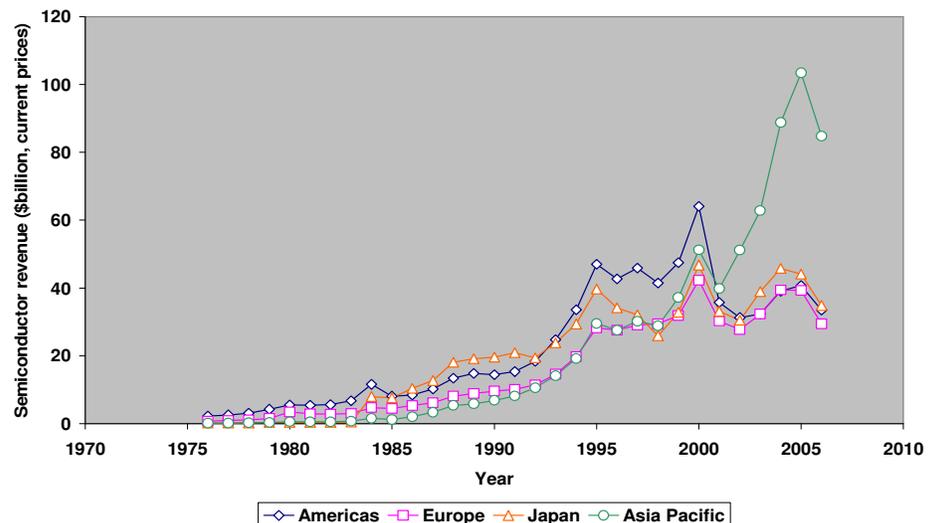
- 3.2.13 In China, while the offshoring and outsourcing activities of multinational companies (MNCs) have dominated, an indigenous independent design sector has emerged; initially in handset design, but now spreading into consumer electronics. Mostly located in Beijing, Shanghai and Shenzhen this sector is at an early stage of development and consists of firms started by former employees of OEMs, entrepreneurs returning from the US or Europe, or joint ventures with foreign OEMs that take an equity stake in the company (Electronics Supply and Manufacturing 2006). Taiwan is the largest source of investment funds. Many of the companies are very small, but a number of them provide services to global companies such as Nokia and Motorola. Companies such as Linpo, with a turnover of more than \$60 million and employing 20 design engineers, combine design with traditional component distribution. Cosmobic is an example of a 3G handsets joint venture between Huawei Technology, NEC and Panasonic, which licenses the 3G core technology and protocol stacks, and delivers the applications to third party handset makers. CEC Wireless is a joint venture between China Electronics Corporation, a state-run body, and Cellon International, a California-based independent design house. CEC provides services to handset makers such as Eastcom, Konka, LG and Siemens, and has an estimated revenue of \$85 million after only six years in operation.
- 3.2.14 In addition to the growing potential for collaboration with indigenous Chinese design companies, China is hosting rapidly growing indigenous OEMs in many sectors requiring substantial electronics design. These indigenous OEMs present a potentially large market for UK design companies who can provide more complex designs than the indigenous Chinese design companies.
- 3.2.15 India has also experienced a rapid growth in its electronics and embedded software sector. Like most other emerging regions, the return of IC designers from Silicon Valley and other established design clusters has been central to its success as an IC design cluster. Those designers have brought with them the required development skills and the contacts in the customer base. The Indian success in software development and, increasingly, in embedded software, has led to independent design companies in Silicon Valley, the UK and other regions completely withdrawing from some market segments.

3.3 The growth of the independent design market

3.3.1 The considerable growth of the semiconductor market over the past three decades, following the introduction of the radically new semiconductor components – microprocessors – can be attributed in part to the rapid expansion of the personal computer market. IBM entered the personal computer market in the 1980s and became the prime manufacturer. Later it outsourced the production of microprocessors, in which Intel emerged as the major producer. Intel and other microprocessor firms grew rapidly in the 1980s and 1990s, as other final markets such as telecommunications, consumer electronics and the automotive industry expanded the demand for advanced semiconductor devices.

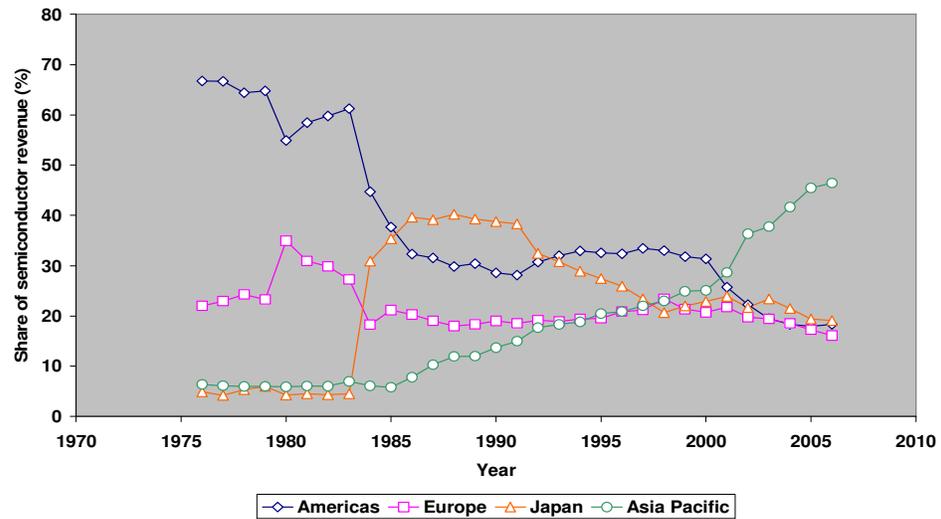
3.3.2 The growth in the market for semiconductors was most rapid in North America in the 1990s, but Asia Pacific has dominated the global market since 2001 (Figure 3.3 and Figure 3.4). The Asia Pacific region's increased share of world markets was gained primarily at the expense of the US. Europe's share has been relatively stable in the past twenty years, in part due to the growth of automotive electronics (European Semiconductor Association, 2006). These overall trends are mirrored in the wider electronics industry (Figure 3.5), with Asia Pacific's share of output increasing over the period 1995-2005, driven largely by China's explosive growth. The share of output attributable to North America declined post-2000, while Europe remained approximately flat.

Figure 3.3 Global semiconductor revenue (\$billion, current prices) by region



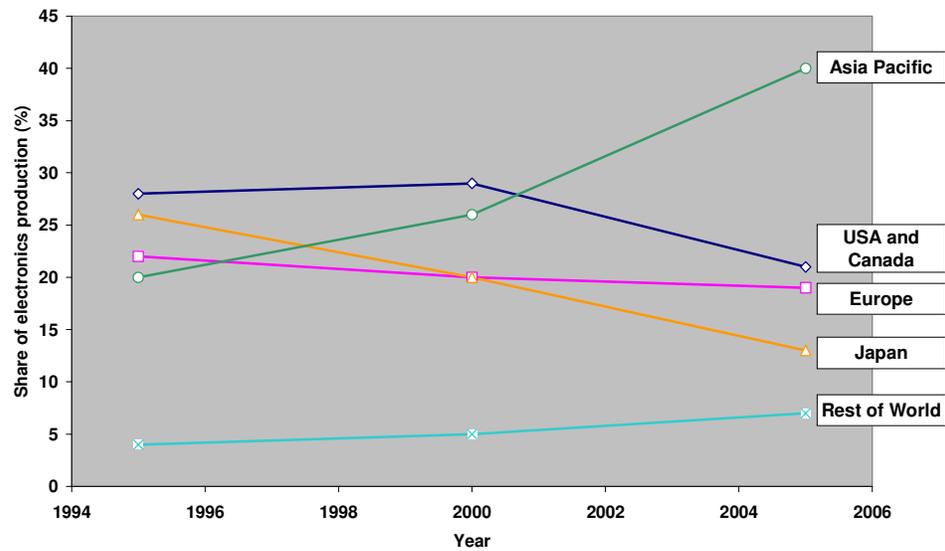
Source: Semiconductor Industry Association

Figure 3.4 Regional share of worldwide semiconductor revenue (%)



Source: Semiconductor Industry Association

Figure 3.5 Share of worldwide electronics output by region, 1995-2005



Source: Yearbook of World Electronics Data

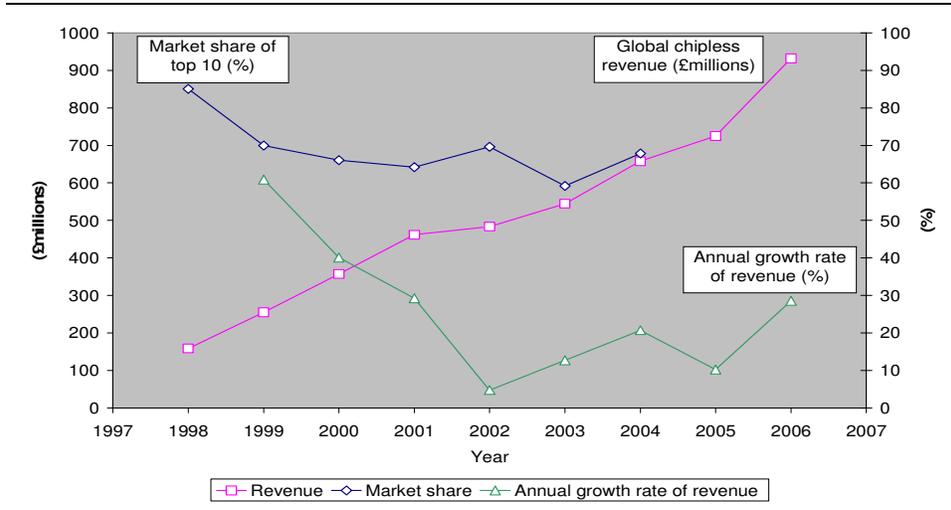
3.3.3

The growth of the global semiconductor market, combined with increasing vertical disintegration is reflected in the growth of the independent design market, as measured by the revenue of the Fabless and the Chipless (SIP) sectors¹². Total revenues of the chipless sector grew steadily, from under £200 million in 1998 to over £900 million in 2006. The annual rate of growth recovered to just under 30% after the slowdown in the global semiconductor industry at the end of the last century. Notwithstanding the sustained growth of the global chipless market, its share of total

¹² Evidence on the scale of the Design Consultancy market is not available at a global level.

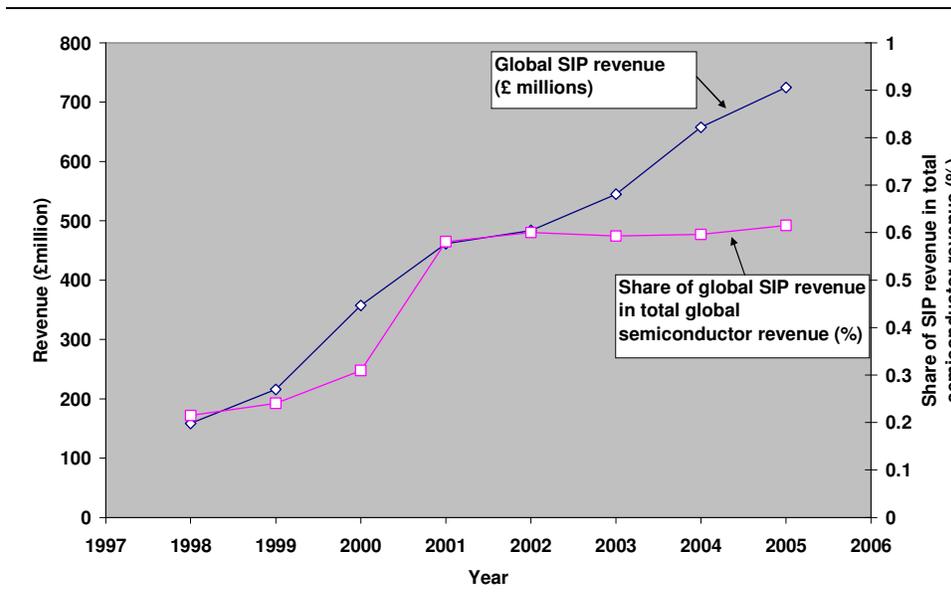
semiconductor revenues has stabilised in recent years (see Figure 3.6 and Figure 3.7).

Figure 3.6 Global chipless revenue (£millions, current prices), annual growth rate (%) and market share of the top ten chipless companies (%)



Source: Gartner Dataquest, reproduced in Design & Reuse, EETimes

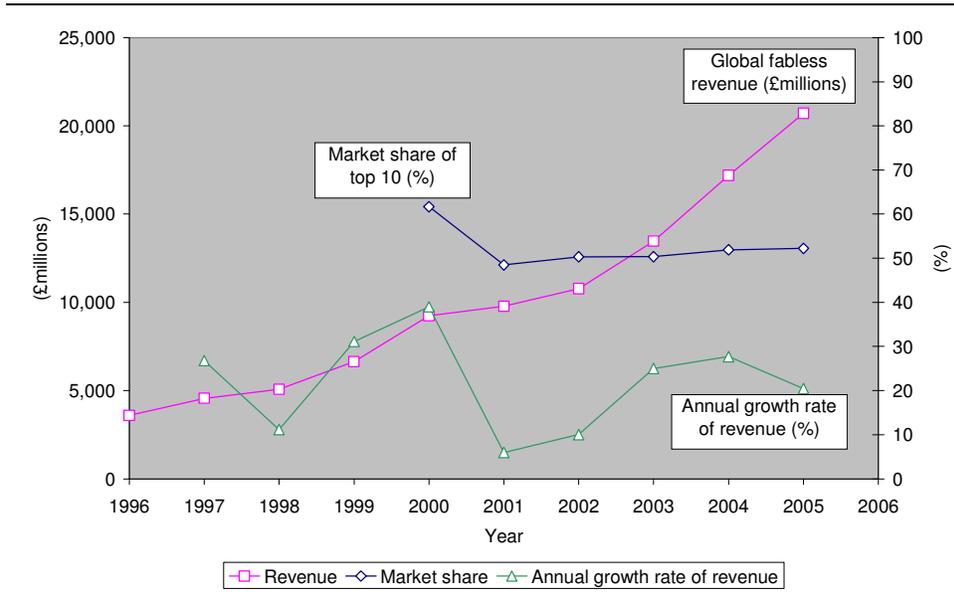
Figure 3.7 Share of global chipless revenue in global semiconductor revenue



Source: Gartner Dataquest, reproduced in Design & Reuse, EETimes

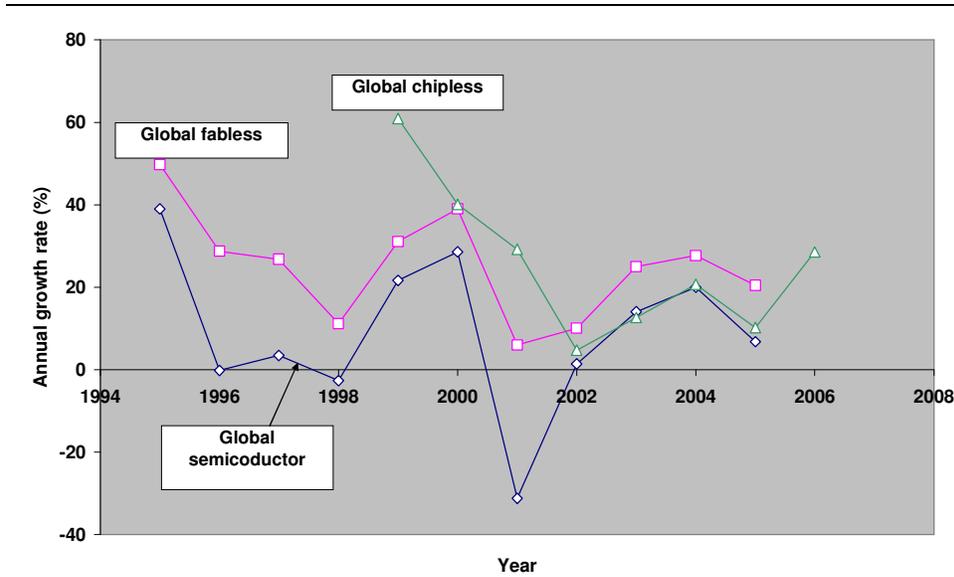
3.3.4 The market for the Fabless sector expanded substantially in the past decade, exceeding £20billion in 2005 (Figure 3.8). Following the sharp decline in growth in 2001, to less than 10%, the fabless market experienced strong recovery with growth of 20% in 2005. Interestingly, the market share of the top 10 global companies has remained largely stable in the past 5 years at just over 50%.

Figure 3.8 Global fabless revenue (£millions, current prices), annual growth rate (%) and market share of the top ten fabless companies (%)



Source: EETimes, Fabless Semiconductor Association, ORBIS

Figure 3.9 Comparison of annual growth rates (%) for the chipless, fabless and worldwide semiconductor sectors

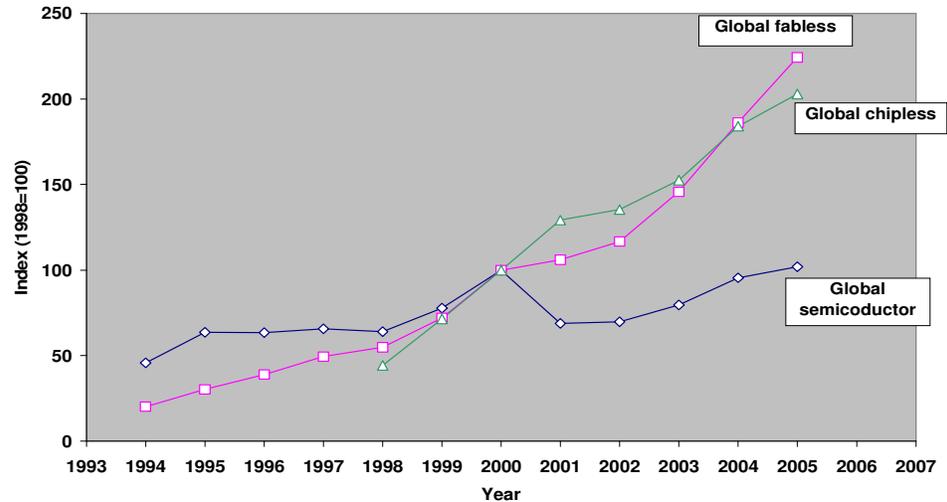


Sources: Semiconductor Industry Association, EETimes, Gartner Dataquest (reproduced in Design & Reuse), Fabless Semiconductor Association, ORBIS

3.3.5 Figure 3.10 demonstrates the increasing importance of the independent design sector in the semiconductor market. Annual growth in fabless revenue has consistently exceeded the growth of overall semiconductor revenue throughout the past decade; and the cyclical pattern of overall semiconductor growth is closely mirrored in the

fabless sector. The chipless market has grown in step with the total semiconductor market in recent years, after relatively rapid growth at the turn of the century.

Figure 3.10 Level growth of global semiconductor, fabless and chipless sectors, indexed to 1998 = 100



Sources: Semiconductor Industry Association, EETimes, Gartner Dataquest (reproduced in Design & Reuse), Fabless Semiconductor Association, ORBIS

3.3.6 The composition of the applications market has shaped the opportunities for specialisation in chip and systems design in the independent design sector. Initially, the main demand for ICs derived from the computer market, which was increasingly being driven by personal computers. However, since the early 1990s, the telecommunications (particularly mobile communications) and consumer electronics (audio, digital TV, PDAs and auto) markets have become increasingly important drivers of demand. In 2004, the global computer industry accounted for 45% of global semiconductor revenue, communications 23%, consumer products 16%, automotive 8%, and industry and government 8% (European Semiconductor Industry Association, 2006). The importance of different applications varies across regions. Europe specialises in applications for the communications and automotive sectors, accounting for 36% of the global automotive semiconductor segment. The share of semiconductors in the total value of the car is increasing constantly. In 2000, it represented approximately 18% of the \$1,000 electronics system¹³; and MEDEA+ and others have projected the value of vehicle electronics to increase to 30% of the total value of the car in the near future.

¹³ MEDEA+ Newsletter November 2001

3.4 The outsourcing of design activities

- 3.4.1 Increasingly, single companies do not handle all stages of design for a specific chip. Instead, there is vertical specialisation, whereby IC design stages are outsourced and relocated across national boundaries. The disintegration of the supply chain raises important questions about the opportunities for the UK independent design sector.
- 3.4.2 The previous chapter distinguished four broad areas in the design process - entire system design, chip design, PCB design and software design. Modularisation of the design process (see Section 3.5 below) provides opportunities for different activities within these areas to be outsourced/offshored. With PCB-based systems, IC designs are embodied in different electronic components which are then integrated onto a PCB. Innovation is incorporated in individual components including IC and PCB design, both of which may be outsourced/offshored. Different electronic functions (processor, memory, protocontrol converters, signal processors etc) can be integrated on one chip (system-on-chip (SoC)), in which case the outsourced design activity supplies licensed intellectual property or design modules (DMs), rather than electronic components (Linden and Somaya, 2003). In addition, other services such as software and systems design may be outsourced.
- 3.4.3 Evidence on the frequency of design outsourcing, the type of third party providers and the activities outsourced is provided by a recent survey of over 300 readers of Electronic Engineering and Electronics Supply & Manufacturing carried out in the US in December 2005. The survey included companies ranging in size from less than \$10million (40 companies) to more than \$1billion (18 companies), with a median size of \$20 million. Over half the companies were OEMs or ODMs, 23% were IDE firms (design consultants, fabless or chipless), with the remainder either EMSs, IDMs or foundries. About 97% had internal design locations in the US, 18% in Europe and 18% in Asia.

3.4.4 Some key findings from the US survey are shown in Panel 3.1

Panel 3.1 Key findings of the US survey	
1	Outsourcing of design is most frequently to firms located in the US (80%), but 31% of respondents said they outsourced to firms in China/Taiwan, 23% to India and 18% to Western Europe.
2	Of 187 companies currently outsourcing or planning to, 41% reported that 30% of their design projects undertaken in the past year included some outsourcing, and this was expected to grow to 48% in the next two years.
3	Of 191 companies that currently outsource or plan to, software design was identified by 60% of companies, board level design by 55%, and chip level design by 40% of companies. Some 29% outsourced entire system design.
4	Some 65% of firms currently outsourcing chip design used design consultancies, 45% fabless semiconductor vendors, 32% foundries, 32% ODMs and 20% EMSs.
5	For board level design, 78% of those currently outsourcing used design consultancies, 32% ODMs and 26% EMS providers. Foundries and fabless semiconductor vendors were cited by 10% and 9% of respondents respectively.
6	Design consultancies dominated the outsourcing of software design, being used by some 86% of those currently outsourcing, while 23% used ODMs and 14% EMSs.
7	Entire system design outsourcing was undertaken primarily by design consultancies and ODMs, with 57% and 53% citing these third party providers.
Source; EE Times (2005)	

3.4.5 The evidence on US outsourcing activities is important because many UK firms in the electronics design sector have significant markets there. A clear message from this survey is that substantial market opportunities exist in the US across a range of markets in the design supply chain. The vast majority of firms outsource domestically rather than offshore and outsource. Standardised design tasks where potential IP leakage is low such as physical design, are clearly the most frequently outsourced although design at 90nm line-width are less likely to be outsourced because of the technical requirements of atomic level wiring, or the complexity of the design. By contrast, architectural design containing proprietary algorithms are much less likely to be outsourced. Considerable effort is made to protect design IP through software/firmware/hardware implementations. Figure 3.10 describes the outsourcing of design activities for the development of electronic products.

Source: PACEC, Chang and Tsai (2000)

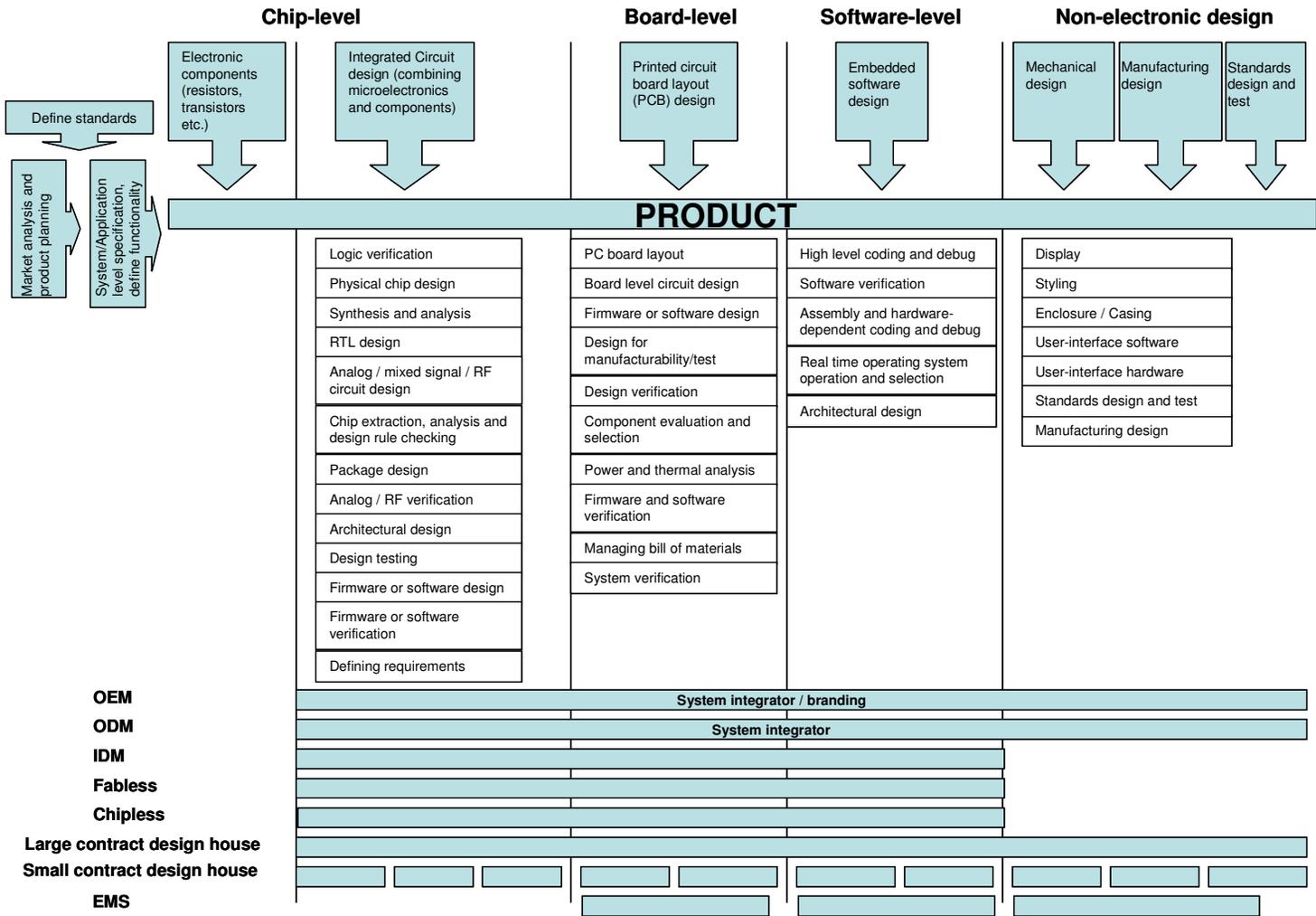


Figure 3.11 Outsourced design activities for the development of electronic products

3.4.6 Further evidence on the pattern of design outsourcing comes from the postal survey of the UK independent design sector undertaken as part of this current study. Entire system design, where the complete design is outsourced to a single provider, is seen as providing the greatest potential opportunities for the growth of the independent design sector. This is particularly the view of the chipless and fabless companies, compared with the contract design houses. Outsourcing of software and chip-level design was also seen as providing potential growth opportunities for the sector. In contrast, relatively few respondents saw the design of printed circuit boards as providing the greatest potential for the growth of the independent sector (see Table 3.1 and Figure 3.12).

Table 3.1 Growth potential for different areas of design for the Industry

	Percentage of all respondents (by type of company)			
	IDS total	Chipless and Fabless	Contract design house	Other
Entire system design	48	60	44	100
Software	43	80	31	60
Chip-level design	38	80	25	60
Design Tool design (e.g. EDA)	10	20	6	40
Board level design	10	0	13	20
Other	14	20	13	0
<i>Number of respondents</i>	<i>21</i>	<i>5</i>	<i>16</i>	<i>5</i>

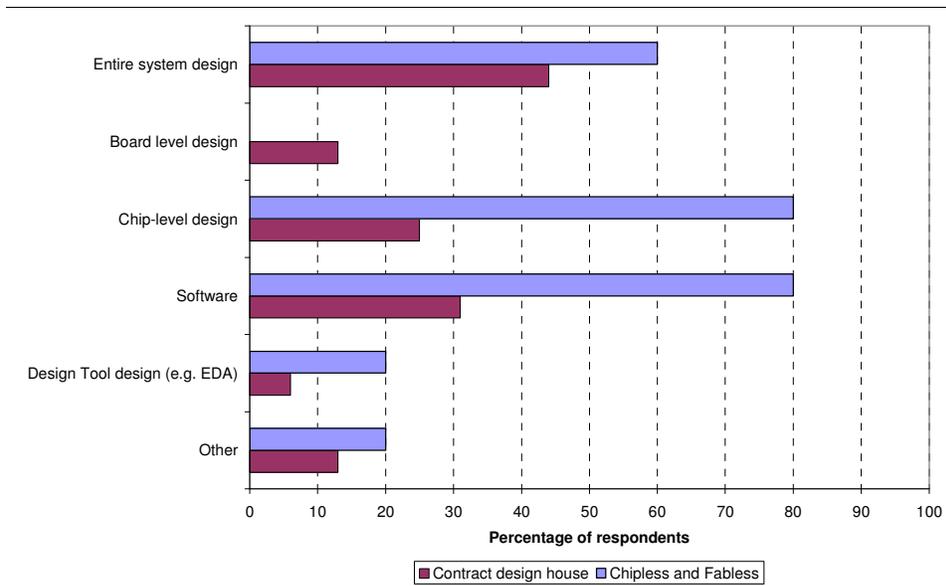
A number is shown in bold where, taking into account the margin of error due to sampling, we are 95% certain that it is different from the number in the left hand total column (using a Chi-Squared statistical test)

Source: PACEC Survey

Question: Which areas of design do you see as having the greatest growth potential for your company and the industry as a whole? (Please tick as many as apply in each column)

Number of respondents: 21

Figure 3.12 Growth potential for different areas of design for the Industry



Source: PACEC Survey

Question: Which areas of design do you see as having the greatest growth potential for your company and the industry as a whole? *(Please tick as many as apply in each column)*
 Number of respondents: 21

- 3.4.7 A majority of companies in the UK independent design sector also expected their customer base to increase the outsourcing of design (Table 3.2).

Table 3.2 Proportion of work being outsourced by customers

	Percentage of all respondents (by type of company)			
	IDS total	Chipless and Fabless	Contract design house	Other
Increase?	57	60	56	80
Decrease?	5	0	6	0
Stay the same?	38	40	38	20

Source: PACEC Survey
 Question: In the next 5 years, do you see the proportion of work your customers outsource as increasing/decreasing/staying the same? *(Please tick one)*:
 Number of respondents: 21

A case study: different organisation modes of design

- 3.4.8 The potential to organise the design process with different design outsourcing strategies was illustrated by Dibiaggio (2006) who carried out case studies of two semiconductor companies developing the same chipset. Company A was an integrated manufacturer based in Silicon Valley, and Company B the semiconductor organisation of a European consumer electronics manufacturer. Both companies were engaged in developing a single chip (SoC) for mobile communications, covering telephony, paging, messaging and Internet. Company A could be described as 'typical Silicon Valley', demonstrating high organisational flexibility, favouring open co-development of design through close collaboration with chipless companies, such as ARM, and high management autonomy. Company B favoured internal type market relationships, limited managerial responsibility by design teams, with conflicts resolved at Board level. Company A shared the knowledge integration process with partners, whereas Company B handled systems integration internally, outsourcing loosely-coupled design modules to specialists.

- 3.4.9 The design flow was broken down into four phases:
- 1 Define expected functional performance of the product, technical requirements, architecture of the system and partner tasks.
 - 2 B outsourced this task to consultants, A co-operated with downstream partners.
 - 3 Implement all functional prescriptions defined by the macroarchitecture at the hardware level, including interfaces between modules and components, and establishment of the design path for all partners.
 - 4 B undertook systems integration by itself, whereas A involved ARM and DSP (software tools) in knowledge integration. System integration was kept in-house in A. Knowledge was freely available to A's partners but not B's partners.

- 5 Design of core chip and implementation of the hardware of the IC. Development of software to integrate different tools or functions in the system.
- 6 Some outsourcing by A and B, but more was kept in-house by B.
- 7 Layout established in preparation for manufacturing

3.4.10 What stands out when comparing the organisation of the design process between companies A and B is the much greater use of outsourcing and collaboration with external partners by Company A. In part this reflects differences in corporate governance between the two companies, but also differences in the mechanisms through which systems integrators integrate dispersed sources of knowledge and manage inter-firm relationships, Dibiaggio (2006). These differences are illustrated in Figure 3.13.

Figure 3.13 Design activity and its organisation for a system on chip (SoC) for a mobile handset

	Knowledge Integration				Design Development Flow			Tools Flow						
	PHASE 1		PHASE 2		PH ASE 3									
	Architecture and Benchmarking	Macro-architecture Instruction set Mnemonic	Micro-architecture	S/W architecture	RTL	Logic Synthesis	Gate Level	Simulator	Assembler Linker	Debugger	C- Compiler	Emulator	Debug	
Co. A	Yellow	Yellow	Yellow	Yellow				Yellow	Red	Yellow	Red	Yellow	Yellow	→
Co. B	Red								Red		Red			→

Key:

	Made in-house
Yellow	Co-operation
Red	Outsourced

Source: based on Dibiaggio (2006)

3.5 Factors underpinning outsourcing and offshoring of design

3.5.1 The evidence presented above indicates that a substantial and sustained shift in the organisation of the design of semiconductors, electronics components and systems has taken place in recent decades. Many more companies outsource their design requirements as part of a process of vertical disintegration of the production process, and significant shifts are taking place in the global location of many activities in the design process. It is important for the independent design sector to understand what factors are driving and enabling these changes, and whether the impact of these factors will intensify or attenuate.

- Will outsourcing continue to drive the market for the independent design sector at rates observed in the past, or will it stall or even reverse with changes in design methodology or new technologies?
- Will design follow production and assembly to China, India and other low cost countries which are experiencing rapid growth in the production and consumption of electronic products and other products and services using ICs?

Outsourcing

3.5.2 We begin with a brief discussion of modularisation. The decoupling of semiconductor design from the manufacturing of semiconductors and the emergence of Fabless and Chipless firms provides a classic example of how modularisation (or the decomposition of the different activities in the production process) enabled outsourcing and the vertical disintegration of the production process. A necessary requirement for the outsourcing of design is the potential to modularise or decompose the production and design processes into different 'modules' that can be developed by different teams working in parallel with interdependence between design tasks within modules but not across modules. Although there is no simple mapping of the extent and nature of modularity in the design process and the organisation of design (i.e. organisational modularisation), it is clear that the modularisation of semiconductor design has enabled many specialised firms to specialise within the wider electronics innovation system.

'Progress in design methodology (technical modularity) has created new opportunities for vertical specialisation (organisational modularity) in project execution, enabling firms to disintegrate the value chain as well as to disperse it across firm boundaries and geographic borders' Ernst (2005).

The outsourcing of different design activities identified in Figure 2.4 and Figure 3.13 provides evidence on the degree of modularisation in design and the nature of the design tasks currently being outsourced.

3.5.3 The emergence of specialist suppliers of complementary services, such as tools for electronic design automation (EDA) and the testing and development of embedded software, further exemplifies the organisational and market outcomes enabled by

modularity in the design process. The development of such areas has also been important in facilitating specialisation and increasing opportunities for outsourcing. For this, access to EDA tools is critical and this has been provided, albeit at high cost, through the emergence of tool vendors such as Synopsis and Cadence.

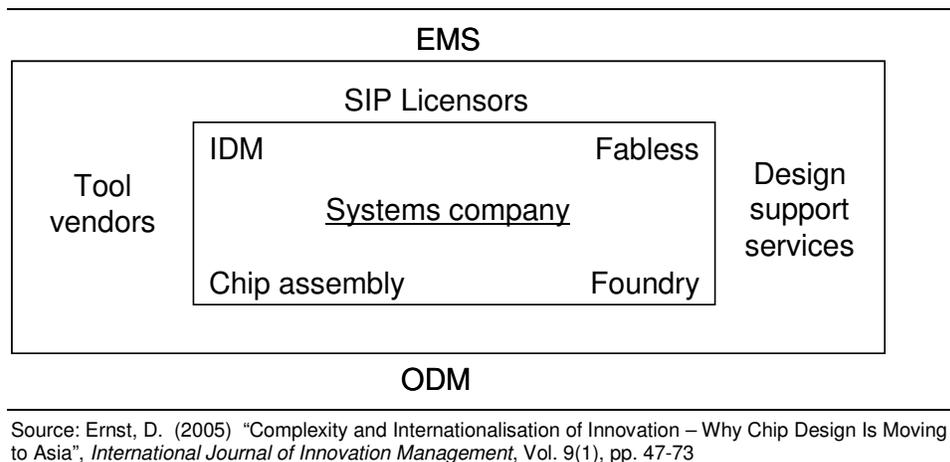
- 3.5.4 Modularisation has also been facilitated by the emergence of 'standardisation' around a single production technology, such as Complementary Metal Oxide Semiconductor (CMOS) processes, which were initially used in the early 1970s in calculators and watches, and in the 1980s for logic chips (Dibaggio, 2006). The emergence of standard CMOS in the 1980s greatly reduced the problems of integrating new components based on different process technologies. Combined with the emergence of complementary design software, this standardisation around a common technology was an important factor that enabled the decoupling of semiconductor design and manufacturing (Macher et al (2002)). The development of standardised interfaces among components not only facilitated specialisation in the production of electronic components, but also gave added momentum to vertical specialisation in component design; with separately designed ICs able to be assembled on a printed circuit board (PCB) for use in the end product. These developments in the standardisation of interfaces in turn encouraged modularisation and specialisation.
- 3.5.5 Although technological developments may permit and facilitate modularisation, it is not necessarily the case that such developments translate into decisions to outsource. Chesbrough (2006) suggests that a number of conditions must be met for outsourcing and market transactions to occur. Firstly, knowledge of internal modularity must be diffused to different agents in the industry, such that the interactions between the components in the architecture are understood. Customer-provider collaboration is one important mechanism for securing this knowledge transfer. Secondly, the required attributes of the components in the system must be unambiguously and clearly specified, so that transacting firms can communicate their requirements. Advanced tools and equipment may be required to verify that the requirements have been met. Lastly, there needs to be a capable supplier base, permitting the switching of providers.
- 3.5.6 However, even if the appropriate conditions for outsourcing prevail, very high technological interdependence and increasing product complexity may mean that optimal design can only be achieved iteratively with very close interactive working and tacit knowledge transfer, making it difficult for outsourcing and the development of an intermediate market. Thus, although the evidence indicates widespread and increasing outsourcing of semiconductor and applications design across a range of design activities, an important question is whether recent technical developments and greatly increased design complexity may slow down, or possibly even reverse this trend towards yet greater specialisation in design. The question arises, firstly because of a growing recognition that technical developments may set limits to increased design modularity. In the past this has been an important factor underpinning specialisation in the design process (Ernst, 2005). But secondly, it arises because further modularisation creates a much greater need for interaction, co-ordination and co-operation between design engineers, mask makers, foundries

and IP block providers. Arguably, this calls for more integrated forms of organisation rather than greater specialisation and outsourcing.

- 3.5.7 Chesbrough (2006) argues that when new product architectures emerge, for example in response to technological change, the transition to the new architecture impacts on the process of product modularisation, shifting it from modular design architectures to interdependent architectures. This, in turn, may shift the focus of design back in-house. Chesbrough (2003) focuses on the dynamics of modularity, and argues that the evolution of technology is cyclical and repeatedly moves from interdependent to modular design architectures. An example would be the shift from a PCB design methodology to a SoC design methodology. SoC is concerned with putting large-scale systems on a single chip, and is enabled by technological changes permitting increases in the number of transistors that can be feasibly accommodated on a single chip. This increasing 'silicon real estate' enables greater memory and power, permits the combination of multiple functions on an IC, and is critically important in extending the applications of semiconductors to a wide range of electronic and other consumer products.
- 3.5.8 The resulting shift to new architectures is typically associated with less modularity at their early stage of development, and technical interactions can be more easily understood and problems resolved in integrated organisational modes. As understanding of these interactions increases and common interfaces emerge, modularisation increases. This increases the potential for vertical specialisation and reduces the advantages of integration.
- 3.5.9 There are important limits to modularity in design and, therefore, to the opportunities for outsourcing to the independent design sector; in addition to the constraints arising from transaction costs, which are discussed below. Ernst (2005) argues that the three important constraints arising from current technological advances, and which give rise to new challenges confronting the organisation of design in the electronics sector are: demanding coordination requirements; constraints to interface standardisation; and conflicts of interest between an OEM/systems integrator and its modular suppliers of design.
- 3.5.10 These constraints may result in a return to more vertically-integrated modes of production and design, particularly for companies (mainly large) which have strong internal capabilities in emerging design technology. However, a return to vertical integration is but one possible management response. An alternative organisational mode is that of iterated co-design within global design networks (GDNs) (Figure 3.14); in which suppliers play a more active role through concurrent engineering, benchmarking, co-location of engineers and redefining interface specifications (e.g. data definition, formats, protocols, performance requirements) for knowledge and information exchange (Ernst (2005), Sabel and Zeitlin (2004)). The different functions integrated into a chip derive from different groups, some in-house, others from outside the company and will include for example, providers of IP, software developers, EDA vendors and foundries. The GDNs are characterised by close

interactions between the different partners in the network, the extent of which will depend on the complexity and maturity of the technology.

Figure 3.14 Global design networks – a multi-layered system



Source: Ernst, D. (2005) "Complexity and Internationalisation of Innovation – Why Chip Design Is Moving to Asia", *International Journal of Innovation Management*, Vol. 9(1), pp. 47-73

- 3.5.11 One consequence of this is that in periods when design methodologies are experiencing rapid change, and when modularisation of design processes is becoming more complex and challenging, outsourcing may be curtailed, particularly in companies that retain some systems integration capability. In the absence of these retained capabilities, companies that become reliant on a given product/system architecture may fall into a 'modularity trap', with a potential erosion of their competitive position. However, a second consequence is that companies in the independent design sector must be sufficiently flexible to meet changing technological and market conditions and the requirements of new architectures, particularly at times when technology is undergoing rapid change.
- 3.5.12 Recent developments in chip design methodology such as 'platform' design', in which both individual design building blocks and the best architectures for particular types of products are reused, reinforce the need to retain system integration capabilities. Ernst (2005) argues that 'a combination of process technology, design IP and systems applications knowledge have helped IDMs like Intel, Texas Instruments and STMicroelectronics to develop platform leadership strategies, and compete successfully against the modularity model, as represented by the collaboration between fabless design houses and foundries. The same is true of OEMs like IBM, Nokia and Phillips, who retain strong capabilities in process technology, fabrication, EDA tools and design IP.

Offshoring

- 3.5.13 The evidence presented Section 3.2 above indicated the growing international mobility of semiconductor design. Asia in particular has emerged as a key destination for offshored design from the US and Europe. What is perhaps surprising is that this growing tendency for dispersal is occurring even in design activities that have traditionally been 'spatially sticky'. This stickiness occurs as a result of benefits

arising from geographical clustering (e.g. knowledge spillovers, thick labour markets, accessible suppliers) and, importantly, the requirement for dense knowledge exchange, much of which is tacit.

- 3.5.14 Big differences in salaries between Asia and the US and Western Europe for design engineers has been an important driver of offshoring, even though lower productivity of inexperienced engineers and monitoring and training cost partially reduces the unit labour cost differential. The labour cost comparisons shown in Table 3.3 are intended to provide broad comparisons, although the situation is changing quite fast with salaries for top class design engineers in China increasing particularly rapidly.

Table 3.3 Annual cost of employing a chip design engineer, US \$ 2002

Location	Annual cost 2002 \$	Annual design engineer base salary 2004/2005 (\$)
Silicon Valley	300,000	82,000
Canada	150,000	
Ireland	75,000	
Taiwan	<60,000	30,000
South Korea	<65,000	
China	26,000	15,000
India	30,000	15,000
Japan		100,000

Note: Discussions with an electronics industry expert suggests that the Irish figure underestimates the annual cost.

Source: Ernst (2004) Annual cost includes salary, benefits such as health insurance/options, equipment, office space and other infrastructure ; Annual base salary are for engineers of 5 or more years experience in the US , aged40+ in Japan and design engineers in tend to be younger in the other countries

Transactions costs and their impact on organisational modes

- 3.5.15 If product architecture and design tasks have been developed to the point where the conditions for modularity in production and design have been achieved, the decision to outsource depends critically on the transaction costs being low enough to permit market exchange. Such an approach has been used by Linden and Somaya (2003), and Somaya and Teece (2001) in seeking to understand differences in the cost and benefits between the integrated mode of organisation in which design associated transactions are undertaken within the company, and the component and licensing outsourcing mode where transactions are with other companies selling components or 'IP' licenses.
- 3.5.16 The implications of technological developments, the shift in design methodology for firm strategy, the organisation of design and the structure of the semiconductor and applications industry depend critically on the transaction costs associated with the different organisational modes (Linden and Somaya, 2003). Technological developments may, in some cases, be a necessary condition for product and design modularity, but there is no predetermined mapping into organisational and market modularity. The scale and nature of design outsourcing, and thus the market for the independent design sector depend very much on the transaction costs associated with alternative organisational modes of design provision. Perceptions of the

significance of transaction costs will, therefore, influence the extent to which outsourcing potential is exploited by the integrated firm in seeking to improve its competitive advantage. Equally, which organisational mode emerges as dominant in the independent design sector – chipless, fabless or contract design house – will in part depend on the transaction costs associated with each mode.

- 3.5.17 The transaction costs associated with licensing and components markets, compared with internal governance costs of integration, have been explored by Somaya and Teece (2001). Under the component mode a multi-invention product combines a number of inventions from different firms which are traded across firm boundaries for integration into the final product. For the Fabless firm, the invention is a complete chip design. Alternatively, the invention can be transferred through a licensing mode typically associated with chipless providers, where the invention traded is intellectual property (IP). Under the vertically-integrated organisational mode, the inventions are co-located in the same firm. The scope of transaction costs is shown in Panel 3.2.

Panel 3.2	Transaction costs of alternative organisational modes
The main transaction costs identified in component markets are:	
<ul style="list-style-type: none"> ● Asset specificity relating to physical and human assets needed to integrate a component to a system ● Dynamic transaction costs of informing, coordinating and persuading component suppliers to cooperate in combining their capabilities in response to technological change. ● Team production and monitoring costs 	
In licensing markets the main transaction costs are:	
<ul style="list-style-type: none"> ● Technological inter-connectedness giving rise to problems of co-ordinating and solving design problems ● Slow moving industry standards ● The transference of tacit knowledge ● Diffuse nature of patent resulting in inability to identify and contract with IP owners, without opportunism ● Valuation problems for an invention that is a joint input entitlements leading to time consuming discussions over valuation ● Monitoring and measurement 	

Source: Somaya and Teece (2001); Linden and Somaya (2003)

- 3.5.18 The Internet and the availability of high bandwidth access have also emerged as an important technical development enabling the establishment of Internet-based markets to trade 'blocks' of intellectual property embedded in semiconductor designs, Linden and Somaya (2001). Internet-enabled trading is supporting increased specialisation by design firms in developing application specific blocks of IP and encourage the use of Fabless firms (Macher et al., 2002). Internet-based design is not only facilitated by trading opportunities being provided, but also by the emergence of so-called design environment vendors (e.g. Synopsis' Internet Enabled Systems product) providing EDA and related tools that enabled geographically dispersed teams to collaborate around the clock.

3.5.19 Under the PCB model IC designs are used to make separate physical IC chips that are integrated with each other on a PCB. Transaction costs determine whether components are openly traded and, therefore, whether the integrated or component organisational mode prevails. With SoC and chip design modules (often referred to as 'IP blocks' or 'design cores'), traditional physical componentisation is ruled out as modules have to be integrated in a single design and manufactured jointly, as they are fabricated on the same silicon wafer. However, a form of componentisation has emerged at the intellectual property (IP) level, with the IP of different DMs being designed and traded by different firms. For SoCs the organisational modes are, therefore, either integrated or licensing modes and again the transaction costs play an important part in determining which mode emerges. Either way, this view links technical modularity to organisational modularity and to market modularity. The outcome is to increase the potential for outsourcing and the opportunities for innovative start-up design companies that focus on high mark-up niche markets in the disintegrated value chain. More recently, however, SoCs have become too complex and expensive for many commodity applications, and manufacturers have resorted to System-in-a-Package (SiPs) designs, whereby simpler SoCs are connected and stacked on top of each other in the same package. This, therefore, results in componentisation at two different levels. First, the physical componentisation with different SoCs potentially being designed by different firms before being assembled into the same package; and second, IP componentisation with the intellectual property within each simple SoC potentially being designed by different firms. The extent to which either a single company or multiple companies conduct the entire design of the SiP depends to a large extent on the transaction costs associated with each mode.

3.6 Implications for the UK design sector

3.6.1 The developments discussed above have been of critical importance to the growth and development of the UK independent design sector for several reasons:

- 1 Increases in the scale and changes in the composition of design outsourcing have reconfigured and developed the market in which the UK independent design sector competes.
- 2 The location of the customer base has shifted as offshoring and outsourcing have encouraged and supported the growth of the electronics industry and its supply network across different geographical locations.
- 3 For some segments of the design process, such as overall system specification or design for manufacturing, co-location of design capability and other stages in the production process, are either necessary or desirable for technical or economic reasons.
- 4 Shifts in the global location of different stages of production and the extent of outsourcing are likely to change the dynamics of competition for the UK independent design sector.
- 5 The outsourcing of design increases the opportunity for providing products and services with high switching costs.
- 6 Outsourcing of activities such as design/innovation intensifies, knowledge flows between provider and customer with mutually beneficial implications for the competitiveness of each.

4 The emergence of the UK independent electronics design engineering sector

4.1 Introduction

4.1.1 Design can be supplied in different ways. The innovation system discussed earlier described the different players involved in design, including OEM and IDM in-house design teams, and those that undertake design independently. In turn, companies in the independent design sector can provide their services through a variety of business models. They can provide consultancy services, working on client-specific projects and get paid on a 'time and material' (cost-plus) basis (contract design houses). Alternatively, business models have emerged which exploit the increasing commodification of design that has been facilitated by the increased modularisation and standardisation of design since the 1980s (fabless and chipless). These business models form the basis of the IDE sector in the electronics innovation system (see Chapter 2).

4.1.2 Changes in the market for design capabilities (see Chapter 3) led to the development of three primary design sub-sectors: contract design house, fabless and chipless. The sector is dominated by a small number of influential players, typically focusing on niche technologies. While the UK sector has a small presence globally, it is home to a number of global market leaders in specific market niches. ARM, the UK's leading semiconductor intellectual property provider, is the global market leader. Cambridge Silicon Radio (CSR) is the global leader in Bluetooth technology. In addition, the UK has attracted many of the design centres of foreign-owned OEMs^{14,15}. Leading electronics manufacturers such as Intel, Infineon, STMicroelectronics and Texas Instruments all have design centres in the UK. Toshiba has invested heavily in a UK-based design team with close connections to Bristol University, developing the next generation wireless technologies and related intellectual property.

4.1.3 The aim of this chapter is two-fold: to set the context of the UK response to the demand for design, and to provide evidence on the productivity and financial performance of the sector, together with the supply-side factors underpinning this performance.

4.1.4 The chapter further seeks to answer a number of key research questions:

- What is the scale and nature of the UK response to market opportunities?
- How concentrated is the market?¹⁶
- How have productivity, efficiency and profitability changed in the UK and how does the UK compare to other global regions?
- What supply side factors affect productivity and efficiency?
- Is there a link between turnover, productivity and profitability?

¹⁴ Invest-UK (2000) "Semiconductor and Electronic Systems Design: Investment Opportunities in the UK", October 2000

¹⁵ UK Trade and Investment (2006) "UK Electronics Sector Overview 2005/2006", July 2006

¹⁶ Concentration describes the size distribution of firms supplying a given market. There are a number of different measures of concentration, eg CR₅ measure the market share of the 5 largest suppliers.

4.2 The response to the growing demand for design capabilities

4.2.1 The UK independent design engineering sector generated a turnover of approximately £0.9-1.0 billion in 2004.¹⁷ It comprises at least 200 companies, employing nearly 8,000 people (see Table 4.1).

4.2.2 It is thought that the number of fabless and chipless companies is close to the population total in 2004, but that the number of contract design house represents a minimum. This is because it is very difficult to identify very small consultancies that do not appear on accounting databases, trade association lists etc. It is also likely that a large number of freelance consultants exist that may provide design capabilities through recruitment agencies, or through existing relationships with customers, or by banding together with other freelance designers, creating 'virtual corporations' for a single project.

4.2.3 The three sub-sectors generate a similar proportion of total sector revenue, although the contract design house sub-sector has the largest number of employees. This is due to approximately 1,500 design engineers operating on a freelance basis rather than under the umbrella of a company. In terms of revenue, the chipless sub-sector was the largest in 2004, generating 38% of revenue. The fabless sector generated 28%, and is growing much faster than the chipless sector. It is thought that by 2006 the size structure of the different sub-sectors would have changed. The reasons for the success of this business model will be analysed in detail later on in the report.

Table 4.1 Size of the IDE sector in 2004

	Turnover* (£million)	Turnover share (%)	Employment*	Employment share(%)	Number of registered companies*	Share of number of companies (%)
Electronics IDE sector	950	100	8000	100	200	100
Fabless	270	28	1400	18	35	18
Contract design house	320	34	4300	54	120	60
Chipless	360	38	2300	29	45	23

Note 1: Employment in the contract design house sub-sector includes an estimate of 1500 freelance designers

Note 2: The number of companies in the contract design house sub-sector does *excludes* freelance consultants

* PACEC estimates

Source: ORBIS, PACEC analysis

4.2.4 The 'design engineering' sector appears fairly small compared to other established sectors. However, this part of the report only considers the independent design engineering sector serving the electronics industry. Later chapters will deal with the design engineering sector serving the automotive industry. Design engineering companies serving other industries are outside the brief of this project.¹⁸

4.2.5 The nature of activities undertaken by the IDE sector tends to be highly technologically innovative. There is, therefore, some merit to comparing the size of the IDE sector to the amount of research and development (R&D) in different sectors of the UK.

¹⁷ Based on PACEC estimates

¹⁸ For example, the construction sector (including oil rigs) is an intensive user of design services.

4.2.6 Table 4.2 provides data on average research and development expenditure as a share of sales, for the top ten sectors (as defined by the DTI R&D Scoreboard 2006). The average R&D intensity (R&D as proportion of sales) of the electronic DE companies identified in the Scorecard is comparable to that of the pharmaceutical and biotechnology sector, which has the highest expenditure on research and development both in absolute terms and as a proportion of sales¹⁹.

Table 4.2 Average research and development expenditure in 2005/06

Sector	Total R&D expenditure (£millions)	Average R&D as a share of sales (%)
Pharmaceuticals & biotechnology	6,817	14.3
Aerospace & defence	2,522	8.4
Software & computer services	933	7.3
Technology hardware & equipment	953	6.1
Health care equipment & services	257	5.1
Automobiles & parts	1,249	4.6
Fixed line telecommunications	731	3.5
Electronic & electrical equipment	613	3.1
Chemicals	582	1.9
Media	275	1.9
All companies composite	19,229	1.7
Private IDE companies	n.a.	3.5
Publicly listed IDE companies	n.a.	21.3
IDE sector	n.a.	14.6

Notes:

Sector definitions based on those used in the DTI R&D Scoreboard

The averages for the 'IDE sector' are based on those IDE companies appearing in the top 800 companies for UK R&D

All private IDE companies in the top 800 are foreign-owned

Source: DTI R&D Scoreboard 2006

4.2.7 Five design engineering companies (in the fabless and chipless sectors) feature in the top quartile of the DTI's ranking of companies based on their R&D expenditure, (Table 4.3). ARM leads the table with over £80 million in research and expenditure, and ranks 36th out of 800. Cambridge Silicon Radio is the second largest, with expenditure of more than £35 million in 2005/06 and ranking 68th.

4.2.8 These results suggest that the importance of the design engineering sector goes beyond turnover and employment data. In order to understand its true importance, it is necessary to turn to other measures, such as R&D expenditure and, crucially, the influence that IDE companies have on their customers.

¹⁹ The averages for the design engineering sector are based on those design engineering companies in the top 800. This will overestimate the value for the sector as a whole since R&D intensity is usually lower in smaller firms.

Table 4.3 Company-level R&D expenditure: IDE companies featuring on the DTI R&D scoreboard (top 800 companies for R&D expenditure in the UK).

Company	Sub-sector	Ranking	2005/06 R&D Investment (£millions)	2005/06 Sales (£millions)	R&D as share of sales (%)
ARM	Chipless	36	80.27	232	34.5
CSR	Fabless	68	35.15	283	12.4
TTP Communications*	Chipless	80	29.5	62	47.6
Imagination Technologies	Chipless	111	20.65	35	58.5
Wolfson Microelectronics	Fabless	155	12.5	97	12.9
ARC International	Chipless	246	6.53	10	62.2
CML Microsystems	Fabless	290	5.12	26	19.4
ClearSpeed Technology	Fabless	304	4.65	0	1059.2
Generics Group	Contract design house	315	4.41	16	28.2
Amino Technologies	Contract design house	411	2.81	23	12
IndigoVision	Fabless	537	1.45	4	40.1
Celoxica	Contract design house	559	1.28	4	29.9
Axeon	Chipless	731	0.57	0	235
Private IDE companies (weighted average)					3.5
Publicly listed IDE companies (weighted average)					21.3
IDE companies (weighted average)					14.6

*: TTPCom is now owned by Motorola
 Source: DTI R&D Scoreboard 2006

The export-orientation of the UK design engineering sector

4.2.9 The independent design engineering sector in the UK has become highly export-oriented, especially as the location of the customer base has changed. Export destination markets vary by sub-sector (Table 4.4). Fabless companies tend to focus on Asia-Pacific; chipless companies are split between Asia and the US (with typically little activity in Europe); and contract design houses focussing on the US, Europe and the UK.

Table 4.4 Geographical origin of revenue

Company	Sub-sector	Percentage of revenue from region			
		Europe	USA	Asia	Other
Cambridge Silicon Radio	Fabless	11	5	82	2
Company A	Fabless	5	6	89	0
ARC	Chipless	28	64	8	0
ARM	Chipless	14	43	43	0
TTPCom	Chipless	10 ⁽¹⁾	16	74	0
Company B	Contract design house	35 ⁽²⁾	65		
Company C	Contract design house	66 ⁽³⁾	33	0	0
Company D	Contract design house	60 ⁽⁴⁾	30	10	0
Company E	Contract design house	15	75	10	
Notes:					
1: UK = 3%, Rest of Europe = 7%					
2: UK revenue					
3: UK = ~33%, Europe = ~33%					
4: UK = 30%<50%, Western Europe = 30%>10%					

Source: Company annual reports for named companies, PACEC interviews for unnamed companies

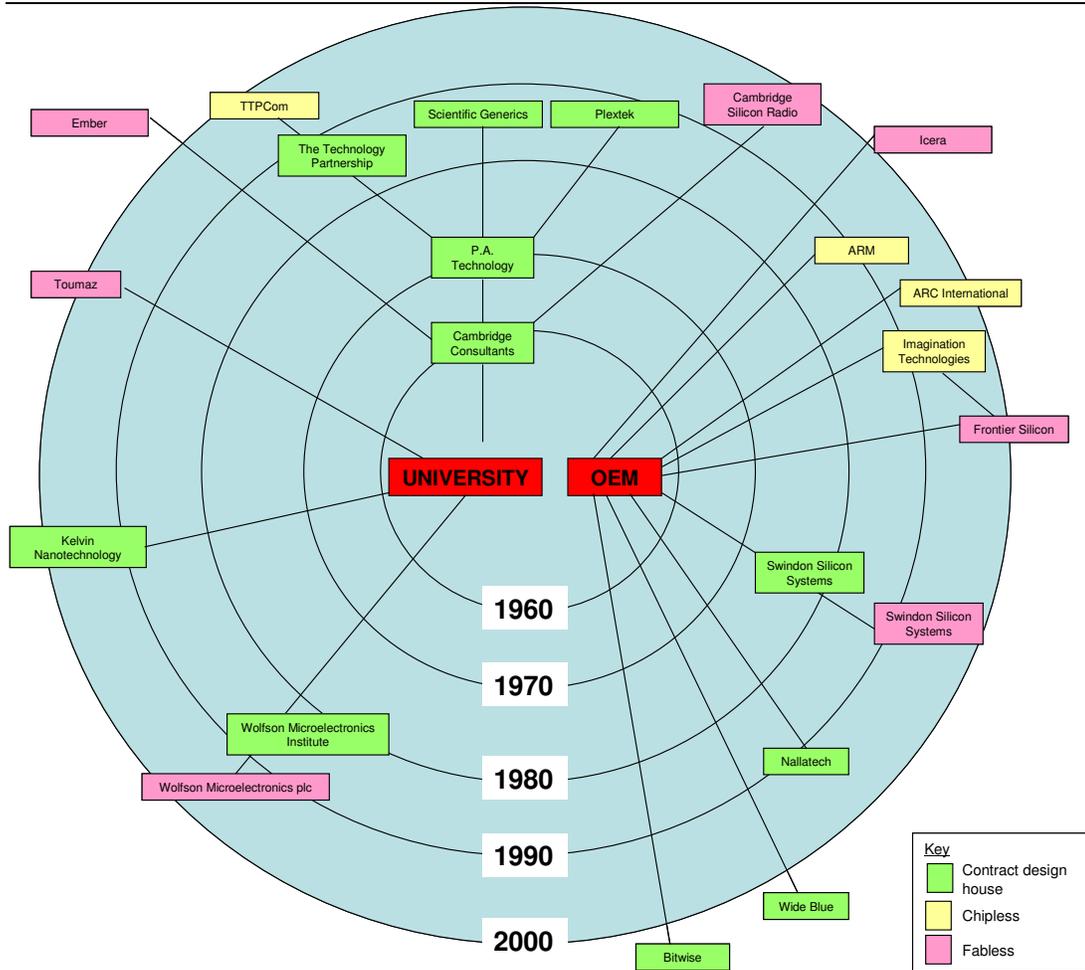
4.3 The contract design house phenomenon

- 4.3.1 This section discusses how the sector has evolved, pursuing different business models. The question why will be discussed in the next chapter.
- 4.3.2 The foundations of the UK independent design engineering sector were laid in 1960, with the emergence of contract design houses after a period of restructuring and downsizing in the UK electronics sector (see Chapter 3). Large and medium-sized UK electrical and electronics companies had faced increasing foreign competition, reduced defence and other public spending, and the growing importance of industries such as telecoms and networking. Internal inefficiencies were exposed in a number of areas, including in-house research, where activities did not always relate to firms' competitive advantage. There was also a growing realisation of the benefits of looking outside the company for technological breakthroughs.
- 4.3.3 Many nationalised companies were privatised, sold, or consolidated into a small number of large European operations, e.g. GEC, ICL, Philips, Racal, Siemens, and Thomson (Future Horizons, 2006). The first casualties of this restructuring were often the managers and highly skilled engineers in research departments.
- 4.3.4 Pure and applied electronics research became the domain of universities and government agencies, while the private sector focused on applied microelectronics research. This led to increased demand for the commercialisation of academic research which, coupled with the increased supply of engineering designers in the labour market, led to the rise of the contract design house sub-sector in the UK. Many recently redundant engineers either left the UK, for example to work the US electronics industry, or formed or joined the fledgling electronics design engineering industry in the UK.
- 4.3.5 For many reasons, not least because of the unwillingness of many engineers to relocate, clusters of contract design houses formed around their OEM and university parent organisations. The key clusters were Bristol and the M4 corridor, the University of Cambridge, and Scotland.²⁰ The success of many of the early contract design houses led to the creation of further companies in the cluster.
- 4.3.6 As an illustration of this process, Cambridge Consultants, thought to be the first technology contract design house, was set up by a number of graduates from the University of Cambridge, with a vision of putting the 'brains of the university at the disposal of British industry and to provide solutions to real world problems'. In 1970, Gordon Edge left Cambridge Consultants to found PA Technology near Cambridge, which spawned a number of very successful local technology consultancies, e.g. Plectek, Scientific Generics (now Sagentia) and The Technology Partnership. Much of the success of the cluster around Bristol can be traced to INMOS and Plessey Semiconductors, both of which attracted engineering talent to the region and led to

²⁰ Although there are now few design engineers in Scotland.

the spin-out of many design companies (NMI, 2003). Figure 4.1 provides an illustration of the origins of some of the larger contract design houses.

Figure 4.1 Origins of the IDE sector



Source: PACEC analysis, Segal Quince & Partners (1985)

Global contenders: the UK contract design house

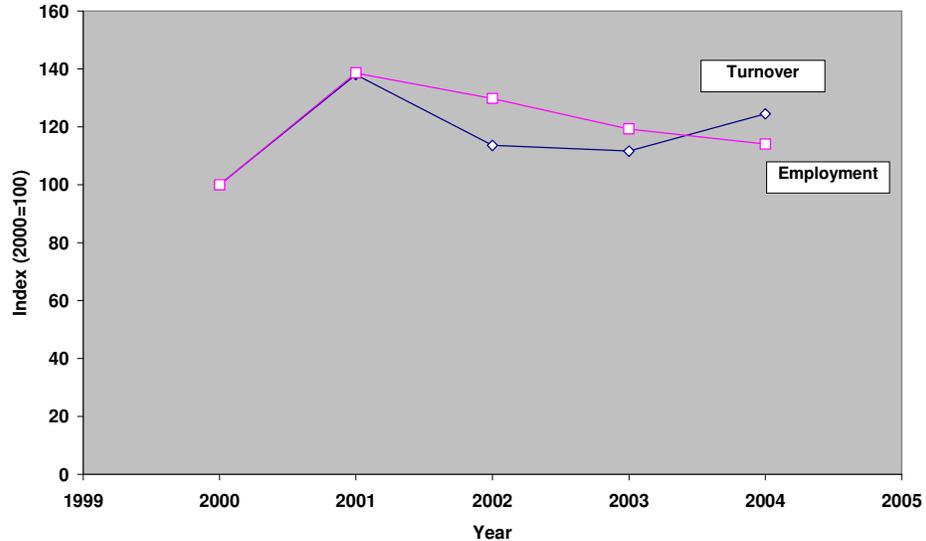
4.3.7 The UK electronics contract design house sub-sector generated about £311 million turnover in 2004,²¹ which is about 33% of the UK electronic IDE sector's turnover. It has nearly 4,200 employees (see Table 4.1),

4.3.8 Figure 4.2 shows how the sector experienced an expansion in 2000 and has since stabilised. Evidence from the case study interviews suggests that head count has not grown for many years in many contract design companies, particularly the larger ones. One reason is that many have encouraged the formation of new businesses by staff members. Recruitment is carried out to replace people who have left, typically as a result of loss to competition, retirement or through corporate spin-outs. The case studies also highlighted difficulties in recruiting people who combine exceptional

²¹ PACEC estimate

technical skills and experience with an interest and aptitude in commercial and business issues.

Figure 4.2 Evolution of turnover and employment for the UK contract design house sector serving the electronics sector.



Index, 2000=100, current prices where appropriate, sample estimates
Source: PACEC analysis, ORBIS

4.3.9 The case study interviews suggest that the large UK contract design houses which undertake full projects successfully compete on the world stage, with many expanding their presence in overseas markets²². It was clear that exports contribute an increasing proportion of total revenues for the larger contract design companies interviewed. Work for UK-based clients now accounts for less than 50% of revenues for many, with the USA the major export market and the Far East growing in importance.

²² To the author's knowledge, no data exists on the global contract design house sector and hence it was not possible to position the UK within the global context in terms of size. This represents an important piece of work for the future.

4.4 Exploiting the commoditisation of design: the fabless business model

- 4.4.1 The fabless business model emerged in the United States in 1984 as a way of avoiding the mounting costs of building and maintaining a fabrication plant (Fab)²³. Under this business model, a company designs and markets the semiconductor integrated circuits, but completely outsources the manufacturing. This business model has only recently emerged and established itself as a viable model in the UK, with the successes of Cambridge Silicon Radio, Wolfson Microelectronics and Frontier Silicon. There were specific reasons for the delayed acceptance of this business model in the UK.
- 4.4.2 The decision to set up a fabless company depends on the market for the product and the feasibility of outsourcing. During the infancy of the fabless sector, the transaction costs involved with satisfying these two criteria would be minimised through close geographical proximity to both the customer base (likely initially an OEM), in order to gain a good understanding of the potential market, and to the manufacturing facilities. Initially, these new 'fabless' companies had to rely on spare capacity within the fabrication facilities (fabs) of the IDMs – use of which was greatly facilitated by the personal relationships that existed between the founders of these new companies and the people responsible for running the fabs. Neither of these conditions were satisfied in the UK in the 1980s, where there was a declining OEM presence and a lack of substantial UK fabrication facilities.
- 4.4.3 The introduction of the independent 'pure-play' foundry in 1987 provided a stable source of manufacturing capacity for chips designed by fabless companies. Their subsequent success greatly helped to further quash the widespread scepticism about whether the fabless model could successfully compete with the fully integrated IDMs by separating design from manufacturing. The foundries reduced the transaction costs of operating at a geographic distance from the manufacturing facilities. It was only once the fabless business model had proved successful that the risk of setting up a fabless company in the UK (at distance from both the customer and the manufacturing facility) was considered low enough to prompt British companies (and companies in other regions) to follow suit.
- 4.4.4 The fabless sector finally emerged in the UK in the early 1990s. With the fabless business model proving a viable method of bringing newly discovered technologies to market in the US, the perceived risks of pursuing such a business model in the UK were now much lower than a decade earlier. Many fabless companies were spun out of contract design houses in order to exploit particular technologies, pursuing a corporate venture with backing from the parent company. The most notable UK success is Cambridge Silicon Radio's emergence from Cambridge Consultants. Other companies, rather than spinning out a new company, altered their business model to exploit the commodification of design. Two notable successes are Wolfson

²³ A foundry is a Fab owned by a third party.

Microelectronics plc, which originated from Wolfson Microelectronics Institute (WMI), and Swindon Silicon Systems. WMI, a spin-off from the University of Edinburgh started as an independent contract design house in 1985 (it had been attached to the electronics department since 1970), winning some high profile contracts (e.g. with Texas Instruments). However, it made the strategic decision to restructure in the mid-1990s and adopted a 100% fabless business model, focusing their chips on the consumer electronics equipment. The company's turnover increased substantially after the restructuring²⁴. Swindon Silicon Systems began life as a design services company in the 1980s. The company was founded by four designers from Plessey Semiconductor in Swindon in order to exploit business that was being turned away by their former employee. In the early 1990s, however, management realised that a majority of their successes derived from repeat designs for their customers, and that by marketing these designs as products, they could achieve much higher returns. This prompted the strategic decision to move towards a fabless business model.

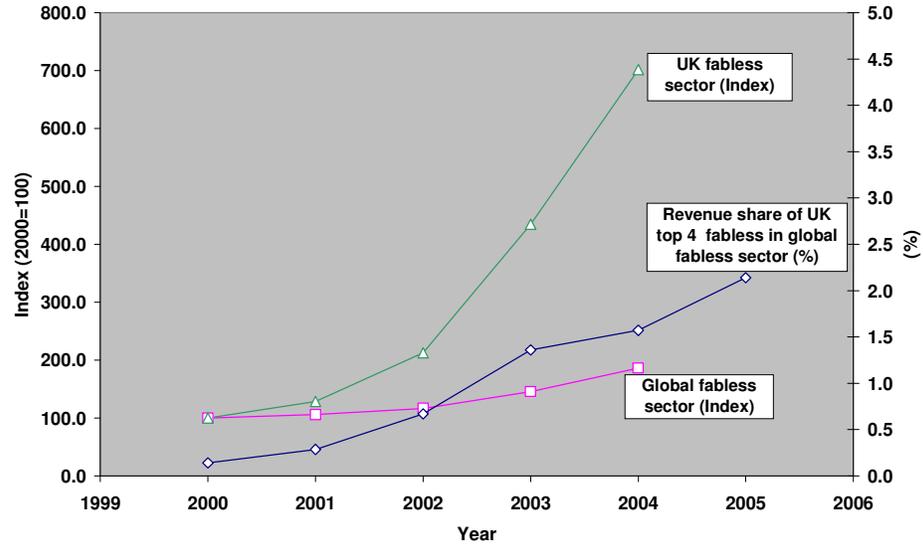
A sector still in its infancy: the global potential of the UK fabless sector

4.4.5 The UK fabless sector is currently growing very rapidly (albeit from a small base) as the business model takes off in the UK. The sector is dominated by the performance of the top five companies, all of whom have grown since 2004. These five alone generated at least £385 million in 2005²⁵ (see Table 4.5). While the sector is very small compared with other global fabless centres (e.g. US and Taiwan), it is still in its infancy. The sector's potential global success is demonstrated by the top five UK fabless companies who, year-on-year, are capturing an increasing share of global revenue and accounted for at least 1.9% of 2005 global revenue (up from a mere 0.4% of revenue in 2001) (see Figure 4.3).

²⁴ Details obtained from Peter Clarke (2005), "David Milne, Chief Executive Officer, Wolfson Microelectronics", published in EETimes, 18 January 2005

²⁵ At the time of writing, no data could be obtained for Oxford Semiconductor for 2005. It is believed that they have not shrunk and therefore have achieved a turnover in 2005 of *at least* £14 million (their turnover in 2004).

Figure 4.3 Comparison of turnover for the UK fabless sector with the global fabless sector, and the revenue share of the top four UK fabless companies* over the period 2000-2004



* UK top four fabless companies in 2004: Cambridge Silicon Radio, Wolfson Microelectronics, Frontier Silicon and Oxford Semiconductor
Source: ORBIS, EETimes, PACEC analysis

- 4.4.6 An aggregate comparison of UK fabless sector and aggregate global turnover suggests that the UK is insignificant on the world stage (generating only 1.6% of global revenue in 2004). This overlooks the fact that the UK has a number of global market leaders in specific market niches. The UK is the global leader in Bluetooth wireless technology, led by Cambridge Silicon Radio (which has secured 45% of the Bluetooth market for GSM mobile phones²⁶), digital audio with Frontier Silicon (which accounts for approximately 70% of all digital audio chips in DAB radios²⁷), and portable audio with Wolfson Microelectronics, which currently supplies a chip for Apple's iPod. Oxford Semiconductor is described as a "world leader in silicon and software solutions for personal storage and consumer connectivity"²⁸. These companies have secured significant market shares in their particular niche, and are generating rapid annual growth in turnover (with the possible exception of Oxford Semiconductor). This suggests that UK companies, while much smaller, have the potential to compete with the large US giants at least in their niches.

²⁶ CSR Analyst and Investor Seminar presentation, 14 Nov 2006 (obtained from www.csr.com)

²⁷ Market share information obtained from: www.frontier-silicon.com/audio

²⁸ Quote obtained from VantagePoint Venture Partners, www.vpvp.com

Table 4.5 Global fabless sector: total revenue (£millions) , top ten global companies, top four UK companies and UK fabless revenue in 2004

Company	2004 Rank	Nationality	2005 revenue (a)	2004 revenue	2003 revenue	2002 revenue (b)	2001 revenue (c)	2000 revenue (d)
Qualcomm	Global 1	US	1,812	1,669	1,300	1,005	722	629
Broadcom	Global 2	US	1,383	1,243	834	561	498	568
ATI	Global 3	Canada	1,151	1,034	717	529	537	710
Nvidia	Global 4	US	1,230	1,041	944	989	709	381
SanDisk	Global 5	US	1,194	920	559	280	---	---
Xilinx	Global 6	US	815	724	655	599	526	859
MediaTek	Global 7	Taiwan	850	664	607	440	237	---
Marvell	Global 8	US	865	634	424	---	---	---
Altera	Global 9	US	582	526	428	368	435	713
Conexant	Global 10	US	---	467	311	270	280	627
Other			9,897	8,271	6,683	5,352	5,043	3,539
Total global fabless revenue			20,710	17,192	13,462	10,770	9,786	9,234
...								
Cambridge Silicon Radio	UK 1	UK	252	136	38	17	12	n/a
Wolfson Microelectronics	UK 2	UK	86	62	77	35	12	9
Frontier Silicon ^(e)	UK 3	UK	24	15	9	n/a	n/a	n/a
Oxford Semiconductor ^(f)	UK 4	UK	n/a	14	13	11	7	7
CML Microcircuits (UK) ^(g)			9	10	9	8	12	14
UK total				270				
UK top 5			371	237	146	71	43	30
Share of UK top 5 revenue in global fabless revenue (%)			1.8	1.4	1.1	0.7	0.4	0.3

Note (a): Conexant was not in the top 10 in 2005. Avago Technologies had a revenue of £932 million

Note (b): Marvell Technology was not in the top 10 in 2002. VIA Technology had a revenue of £377 million

Note (c): SanDisk and Marvell Technology were not in the top 10 in 2001. VIA Technology had a revenue of £522 million and Cirrus Logic had a revenue of £276 million

Note (d): SanDisk, MediaTek and Marvell Technology were not in the top 10 in 2000. VIA Technology had a revenue of £471 million, Cirrus Logic had a revenue of £377 million and PMC-Sierra had a revenue of £360 million

Note (e): Frontier Silicon was founded in 2002

Note (f): At the time of writing this report, turnover data for 2005 for Oxford Semiconductor had yet to be provided on the accounting database

Note (g): CML Microcircuits (UK) is one of eight subsidiaries of CML Microcircuits Plc. Revenue data in this table is for this subsidiary only.

Sources: Fabless Semiconductor Association, EETimes, PACEC Analysis, ORBIS

4.5 The demand for reusable design: the chipless business model

- 4.5.1 The emergence of a sector based on the licensing of semiconductor intellectual property resulted from shifts in both the technological paradigm prevailing in the wider electronics sector, and in the relative importance of different electronics sub-sectors. The 1980s witnessed the rapid increase in importance of the consumer electronics and business ICT markets relative to defence electronics. The shorter product lifecycles, lower margins and higher volatility in consumer electronics increased the importance of time-to-market, cost and the ability to assume high levels of risk for competitive advantage.
- 4.5.2 The wider electronics industry witnessed a rapid increase in the complexity of semiconductor chips, which made it more difficult for designers to utilise the increased capacity of semiconductors (known as the 'productivity gap' problem, see Brown and Linden, 2005:20, Ernst, 2003:8). This factor, together with the increased costs of semiconductor design and time-to-market pressures, led many chip design companies to consider reusing known-to-work designs that could be used in new integrated designs to provide specific functionalities. This approach of building systems around existing designs required the establishment of strong protocols and efficient standardised architectures.
- 4.5.3 The current demand for the intellectual property of microprocessor cores originated in the days of traditional Printed Circuit Board (PCB) technology, but took off once the industry began integrating many system-level functions on a single piece of silicon – the System-on-a-Chip (SoC) – in the 1990s. Under the SoC, the technological module moved from individual physical components that could be designed and produced in relative isolation (consistent with standard interfaces), to the intellectual property of specific functions that had to be integrated prior to manufacture. This provided the opportunity for companies to provide the known-to-work intellectual property of semiconductor circuits (IP blocks) that could be integrated into the larger system.
- 4.5.4 Two further developments supported the emergence of the intellectual property business model. Firstly, CMOS (complementary metal–oxide semiconductor) emerged as the dominant technology in semiconductor process, allowing for the standardisation of interfaces between different microprocessor cores. Secondly, design tools developed sufficiently to allow significant simulation and characterisation of the CMOS process limits of different chip plants, supporting the further separation of design from manufacture (Linden and Samoya, 2003). Without these developments, the integration of semiconductor intellectual property developed by different design teams would have been immensely difficult.
- 4.5.5 The 'chipless' sector really began with the foundation in 1990 of ARM Ltd., a spin-out from Acorn Computers. Acorn designed and developed computers including the successful BBC Micro and Acorn Archimedes, and developed a successful series of

microprocessors known as the Acorn Risc²⁹ Machine (ARM) during the 1980s. Acorn realised that continuing to develop the ARM microprocessor in-house would limit the market because customers would be unwilling to depend on a competitor's microprocessor design. Acorn decided to enter into a joint venture with Apple, a competitor in the desktop computer market. Apple had realised that the Acorn Risc Machine presented the best opportunity of satisfying the power consumption, cost and performance requirements of its new computing platform. In 1990 the majority of the Advanced Research and Development division was spun out to found ARM Ltd., with the mission of developing Advanced Risc Machine microprocessors. By partnering semiconductor companies, ARM could avoid the large costs associated with sales and marketing and concentrate on its competitive advantage: its design engineering skills. Under this business model, ARM supplied the means by which customers could address the market and technological pressures outlined above through a mixture of royalty and licensing.

- 4.5.6 Other chipless companies emerged out of OEMs in a similar fashion to ARM. ARC was spun out in 1998 from the hardware design division of Argonaut, a software provider to leading game companies. The design team had the technology and know-how to design highly customisable microprocessors rapidly. ARC is now the world leader in configurable processor technology³⁰, licensing CPU/DSP processors and multimedia sub-systems for the design of highly differentiated system-on-chips. Other chipless companies, by contrast, resulted from spin-outs from a contract design houses in order to exploit a particular technology thought to have potential in the market.

Global leaders: the UK chipless sector

- 4.5.7 Since its birth, the UK chipless sector has grown to an estimated £356 million in 2004. It generates approximately 38% of the revenue attributable to the UK independent design sector serving the electronics industry (see Table 4.1), making it the largest of the three sub-sectors. However, it is thought that the fabless sector may have since overtaken it due to the very strong performance of Cambridge Silicon Radio, Wolfson Microelectronics and Frontier Silicon.
- 4.5.8 UK chipless firms also dominate the global sector, generating 52% of the estimated £660 million of global revenue in 2004. Table 4.6 highlights both the concentrated nature of the chipless market and the UK's dominance within this market. In particular:
- The global top ten generate approximately 68% of total chipless revenue;
 - Chipless providers are concentrated in two main regions: the US and the UK. While the Far East is a major market for semiconductor intellectual property (and represents the source of 43% of the total revenue of ARM³¹), the region has not yet emerged as a serious competitor³²;

²⁹ Reduced Instruction Set Computing.

³⁰ ARC overview, ARC International website (www.arc.com/company/index.html)

³¹ Figure obtained from the annual report of ARM Ltd. 2005.

³² Evidence based on case study interviews with leading UK chipless companies

- The three UK companies in the top ten generate 35% of total global chipless revenue, 52% of the total revenue generated by the top ten chipless firms;
- Approximately 80% of 2004 revenue generated by the top ten chipless companies was generated by independent semiconductor IP providers (like ARM, TTPCom, MIPS Technologies), while the remaining 20% was generated by semiconductor IP operations within other companies (e.g. EDA companies such as Synopsys, Mentor Graphics).

Table 4.6 Global chipless sector: total revenue (£million), top ten companies and market share

Company	Nationality	2004 Revenue (£millions)	2004 Market Share (%)	2003 Revenue (£millions)	2003 Market Share (%)	Growth (%)
ARM *	UK	161.64	24.5	90.71	16.6	78.2
Rambus	US	75.02	11.4	61.20	11.2	22.6
TTP Com**	UK	53.90	8.2	39.56	7.2	36.3
Synopsys *	US	39.45	6	40.85	7.5	-3.4
MIPS Technologies	US	29.36	4.5	20.92	3.8	40.5
Virage Logic	US	27.44	4.2	21.02	3.8	30.5
Ceva	Ireland	19.93	3	19.05	3.5	4.6
Imagination Technologies	UK	14.81	2.3	12.22	2.2	21.3
Mentor Graphics *	US	14.13	2.2	11.49	2.1	22.8
Silicon Image	US	10.77	1.6	7.35	1.3	46.7
Others		213.06	32.3	222.27	40.7	-4.1
Total Market		659.52	100	546.65	100	20.7

* Note: Revenue figures for ARM, Synopsys and Mentor Graphics in 2003 represent those of the core companies before acquisitions. In 2004, ARM acquired Artisan, an IP company previously covered in this study. Revenue for Artisan in 2003 is included in "Others", while calendar-year revenue for 2004 has been consolidated under ARM. Synopsys acquired Cascade Semiconductors, another IP company previously covered in this study, in 2004. Cascade's 2003 revenue is also included in "Others" while calendar-year revenue for 2004 has been consolidated under Synopsys.

** Note: TTP Com was acquired by Motorola in June 2006. This will not have any effect on the data analysis

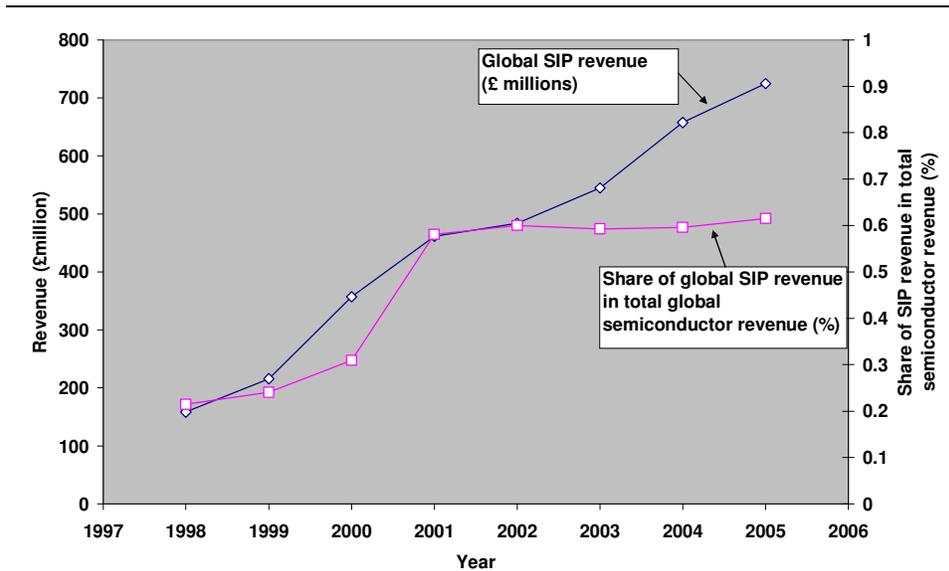
Source: Gartner Dataquest (June 2005)

4.5.9 The chipless market is dominated not only by independent, but also by 'captive' semiconductor IP operations that are part of EDA (and other semiconductor) companies. This demonstrates, to some extent, the blurring of the boundaries between the different players in the innovation system described earlier. Companies are beginning to view the marginal benefits of providing reusable semiconductor intellectual property as outweighing the marginal costs, especially in circumstances where design libraries exists internally. The licensing of intellectual property acts as a useful additional source of revenue. There also appears to be a geographical dimension to this division. UK companies tend to operate as independent providers (ARM, Imagination Technologies, TTPCom³³), while the major US competitors tend to be 'captive' within an EDA company (e.g. Synopsys, Mentor Graphics). However, there is evidence that this may be changing – TTPCom was acquired by Motorola in June 2006, thus adding an intellectual property licensing operation to its capabilities.

³³ Until it was acquired by Motorola in June 2006

- 4.5.10 Table 4.6 raises the critical question of why the global semiconductor intellectual property market is so concentrated. With the emergence of the semiconductor intellectual property market, and the increasing demand for design reuse, expectations emerged that the technical modularity of chip design would lead to both organisational and market modularity. For example, Linden and Samoya (2003: 545) expected a “burgeoning market for licensed [semiconductor intellectual property]”. However, this expectation has not emerged. Ernst (2005) argues that the situation is much more complex; that technical modularity does not necessarily lead to market modularity; and that the “small, ‘boutique shops’ that were supposed to be the main carriers of market modularity, only play a marginal role” (p. 313). Ernst (2005) alludes to a number of factors explaining the failure of the chipless market to spawn these small boutique chipless providers, and divides the factors into three areas:
- 1 High entry barriers to the independent chipless market
 - Independent providers of semiconductor IP face very high financial and human resources investments in order to establish the global partnership network with all the different players involved in chip design;
 - 2 Differentiation of standard semiconductor IP
 - Systems knowledge is now essential in order to differentiate the standard semiconductor IP. The use of embedded software is crucial to the achievement of this;
 - 3 The diversification strategies of EDA vendors
 - As EDA companies face new and increasing challenges to their business models, they are acquiring or developing promising semiconductor IP provider start-ups. An example is the recent acquisition by Motorola of TTPCom, a UK chipless firm in the mobile phone market, and the third largest semiconductor IP provider in 2004 (see Table 4.6).
- 4.5.11 To this can be added the reluctance of customers to accept the risk of incorporating third party IP into the core of their systems from small unproven companies. Furthermore, due to the (high) cost facing the customer of integrating an IP core into their wider system, companies have a limited ability to host many different IP cores. Until the integration costs are greatly lowered, or the above factors described by Ernst (2005) change, the sector will likely only be able to host a very limited number of companies.

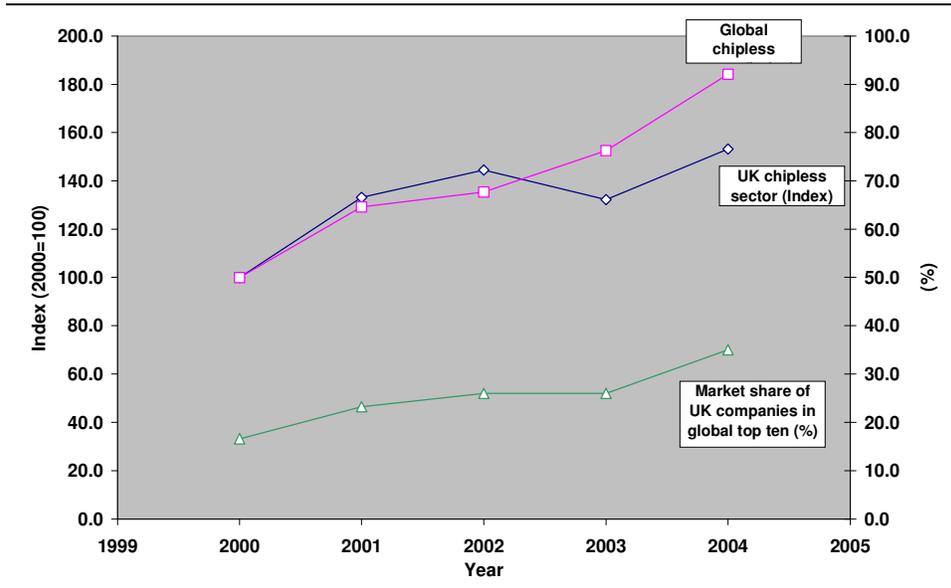
Figure 4.4 Growth of the chipless (semiconductor intellectual property, SIP) market (£million, current prices) and its share in total semiconductor revenue (%)



Source: Gartner Dataquest, EETimes, PACEC analysis

- 4.5.12 Figure 4.4 shows that while the chipless market has been growing year-on-year (with total global chipless revenue standing at £725 million in 2005), its share in total semiconductor revenue remained fairly stable over the period 2001-2005. The UK chipless sector has followed the global revenue trend. Figure 4.5 shows a clearly increasing trend, with the exception of a downturn in 2003 experienced by most UK chipless firms. The compound annual growth rate of turnover for the chipless sector was 11.3% per annum over the period 2000-2004, compared with a growth rate of 16.5% per annum for the global sector.
- 4.5.13 Figure 4.5 also shows the evolution of the UK's market share of the chipless market. It shows that the market share of UK companies within the global top ten increased over the period. This is mainly due to the improving market shares of ARM, TTPCom and Imagination Technologies. This suggests that the UK sector is becoming more concentrated, as a small number of companies secure an ever greater share of the global market while the others fail to keep up although the market is still growing. This will be discussed in more detail later on in the report.

Figure 4.5 Comparison of the evolution of turnover of the global chipless sector along with the market share of UK companies in the global top ten.



Source: Gartner Dataquest press releases, PACEC analysis

4.6 The structure of the UK independent design engineering sector

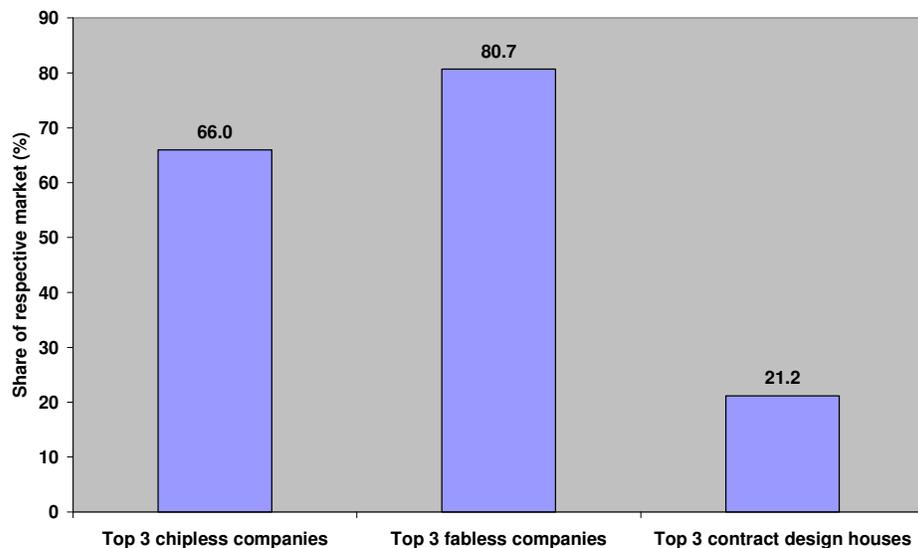
4.6.1 This section focuses on the structure of the sector and how it has changed over the period 2000-2004. It addresses two fundamental questions: is there a dominant business model emerging, and is the sector becoming more concentrated? Why these changes have occurred will be dealt with in later chapters.

How concentrated is the sector?

4.6.2 An important component in the understanding of the competitive dynamics of a sector is its concentration. Previous sections referred to the highly concentrated global chipless and fabless markets, with the global top ten companies generating 52% and 68% of global revenue respectively. The UK fabless and chipless sectors are similarly highly concentrated with the top three companies in each sector generating 81% and 66% of UK fabless and chipless revenue respectively (see Figure 4.6). The contract design house sector is much less concentrated, with only 21% of revenue being generated by the top three, although the top ten companies generate approximately 50% of turnover.

4.6.3 The UK chipless sector is dominated by ARM, which generates approximately 41% of UK chipless revenue. The fabless sector is dominated by Cambridge Silicon Radio, with 51% of UK fabless revenue. The largest contract design house identified is Roke Manor Research, which accounted for approximately 9% of contract design revenue in 2004.

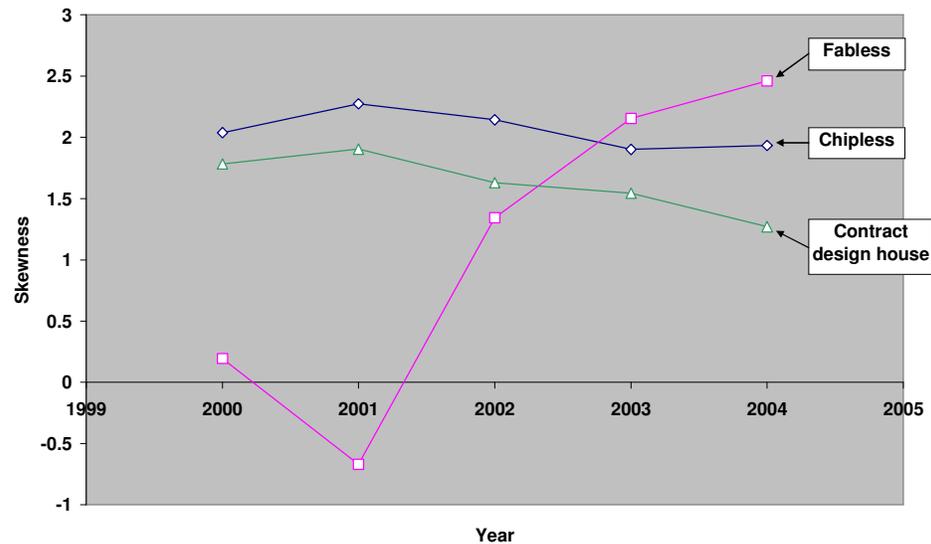
Figure 4.6 Concentration ratios for the fabless, chipless and contract design house sub-sectors in 2004.



Concentration ratio based on the share of the market held by the **top 3 companies** in each sub-sector.
 Source: PACEC analysis. ORBIS, Fabless Semiconductor Association, EETimes, Gartner Dataquest press releases

- 4.6.4 Evidence on whether the concentration of each sub-sector is changing can be assessed by examining the skewness³⁴ of the sector. An increasingly positive skewness indicates a sector becoming more concentrated. Figure 4.7 suggests that the fabless sector is becoming increasingly concentrated as it matures, with the larger companies securing an ever-increasing share of the market. For example, the phenomenal growth of both Cambridge Silicon Radio and Wolfson Microelectronics (and increasingly by Frontier Silicon) is driving growth in the UK fabless sector, with these companies now generating the bulk of the sector's revenue. By contrast, the contract design house sub-sector, already much less concentrated than the fabless and chipless sectors, is becoming less concentrated as it evolves.
- 4.6.5 The structure and dynamics of the sub-sectors vary considerably. Barriers to entry are very low in the contract design house sub-sector, compared with the fabless and chipless sub-sectors. High rates of growth (in either employment or turnover) are less common in the contract design house sub-sector, making it more difficult for individual companies to dominate the sector. The contract design house sub-sector is also much more mature than either the fabless or chipless sub-sectors. It remains to be seen what the future holds for the fabless sector. If CSR, Wolfson Microelectronics and Frontier Silicon foster other success stories, concentration could be reduced.

³⁴ Skewness is the third standardised moment, and is a measure of the asymmetry of a probability distribution. A positive 'skew' indicates that the right tail is the longest and the mass of the distribution is concentrated to the left of the mean. This suggests that the sector is populated by a small number of larger-than-the-mean firms, and a large number of smaller-than-the-mean firms. An increasing positive skewness suggests an increasingly concentrated sector. A negative 'skew' indicates that the left tail is longest and the mass of the distribution is concentrated to the right of the mean. This suggests that the sector is populated by a large number of larger-than-the-mean firms, and a small number of smaller-than-the-mean firms.

Figure 4.7 Changing concentration: the skewness of the IDE sector.

Analysis based on current prices, sample estimates
Source: PACEC analysis, ORBIS

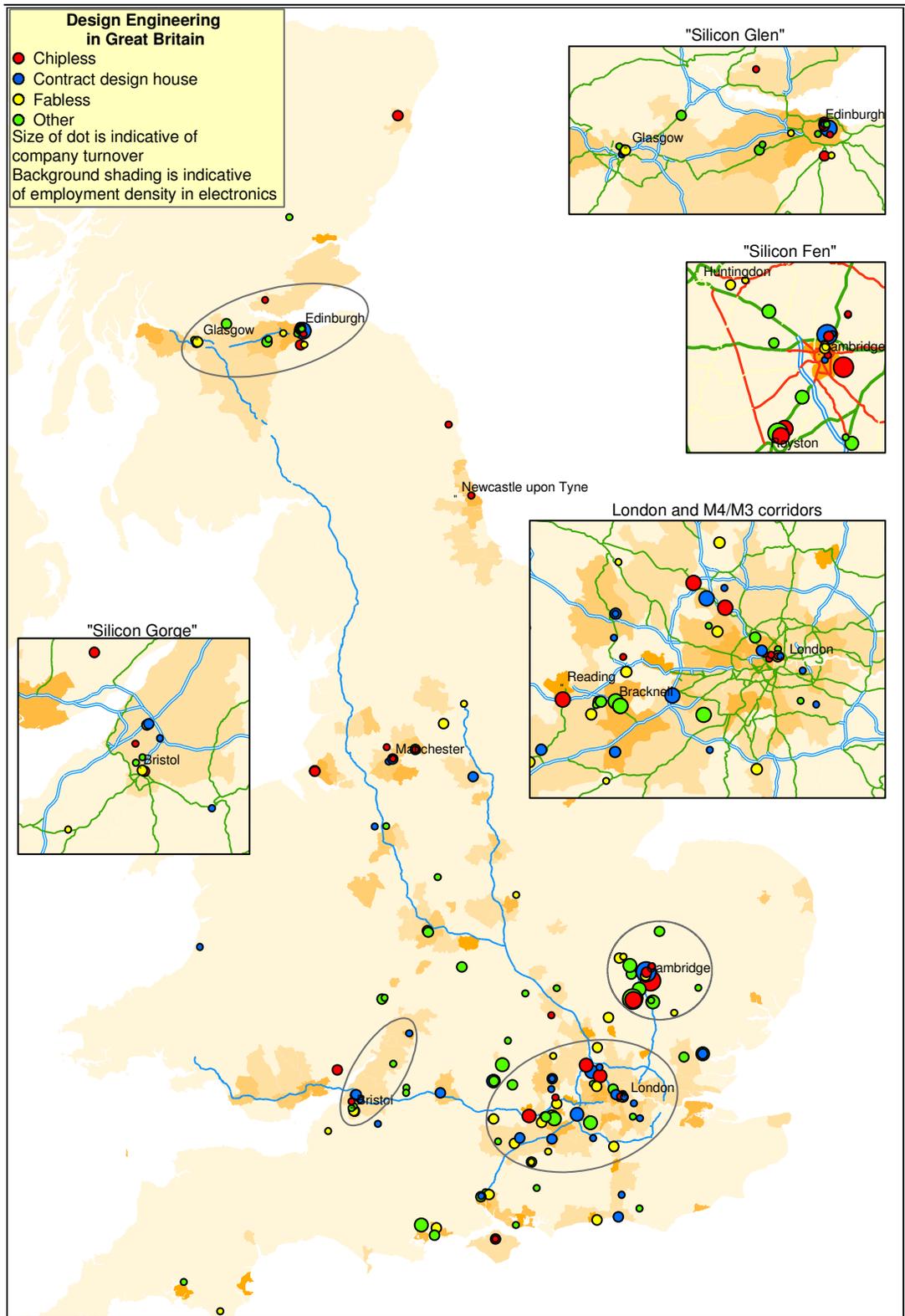
Do independent design engineering companies cluster?

- 4.6.6 Clustering of companies around focal points is observed in a number of industries and has been shown to yield a number of benefits. A focal point could be the customer, a university, international gateways such as airports, or major transport routes (motorways).
- 4.6.7 The IDE sector serving the electronics industry appears to cluster in four main locations (Figure 4.8):
- M4 corridor
 - Bristol, known as “Silicon Gorge”
 - Central Scotland stretching from Edinburgh to Glasgow, known as “Silicon Glen”
 - Cambridge, known as “Silicon Fen”.
- 4.6.8 The emergence of the clusters in these regions was partly due to the locational origins of the founders of the start-ups³⁵. Not only did these regions possess the necessary skills base (built up by the parent companies), but many founders had strong personal ties to the respective areas. By locating close to the parent companies, the new companies were able to maintain and maximise the benefits from personal relationships to secure work and minimise disruption to personal lives.
- 4.6.9 Figure 4.8 also shows the thickness of the electronics labour market in the different regions of the UK (darkness of background shading). It is clear that three of the four clusters are embedded within the wider electronics industries (M4 corridor, Silicon

³⁵ This emerged as a factor in the decision to locate in a particular region in the discussions surrounding the origins of the companies and the personal histories of the founders during interview programme for this study.

Gorge and Silicon Glen), while Silicon Fen is a free-standing cluster. This suggests that while geographical proximity may be important, it is not necessarily crucial. The increasing export orientation of companies may weaken the benefits of being embedded within a wider electronics cluster and strengthen the benefits of being embedded within an R&D intensive region, or being near to international gateways to reduce the costs of accessing global customers.

Figure 4.8 Location of the UK IDE companies

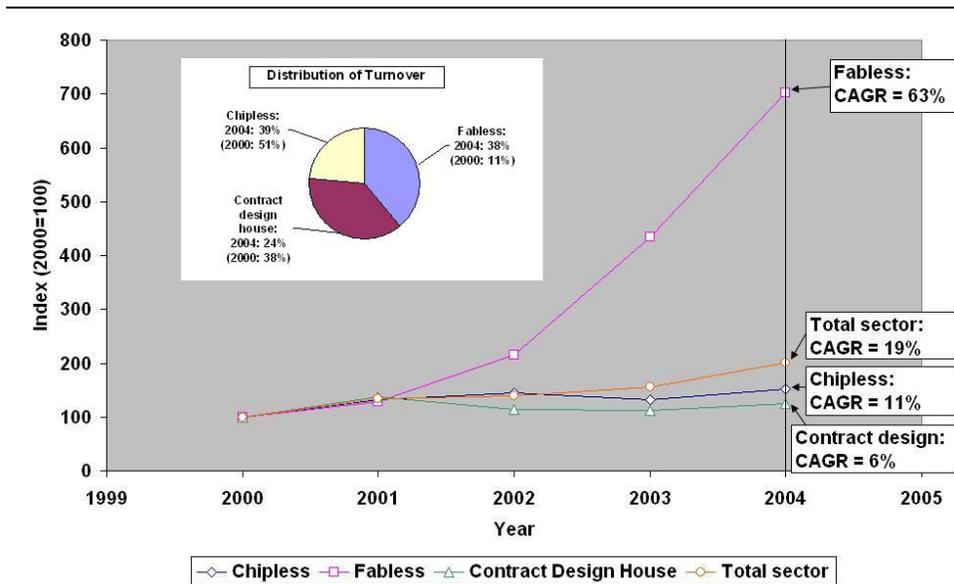


Note: The location of many smaller contract design houses is unknown and could not be represented on this map.
Source: PACEC research, ORBIS

4.7 The blurring of boundaries and the evolution of business models

- 4.7.1 Recent years have seen a blurring of the boundaries between the sub-sectors, as the independent electronics design sector restructures in response to changes in global demand (Chapter 3). For example, as the demand for reusable designs increases (in order to combat the increasing complexity problems and cost and time-to-market reduction pressures), companies find themselves in possession of a vast amount of intellectual property in designs that (internally at least) have been proven to work. The success of the chipless market (as demonstrated by its above average annual growth compared with the semiconductor industry in general) has prompted many companies with these internal semiconductor IP libraries, to license their designs on the open market in search of new revenue streams with low marginal costs.
- 4.7.2 Another example of the blurring of the boundaries is the provision of design tools. Many chipless companies are beginning to offer design tools 'wrapped around' the semiconductor core, which allow customers to customise products as they see fit. In a similar vein, EDA companies are increasingly entering the market for semiconductor IP. The provision of tools alongside the semiconductor intellectual property is a potential method for 'locking' customers into a product, as the costs of subsequently changing provider increases due to, for example the retraining costs for tools and software. The blurring of the boundary between EDA and chipless companies is most apparent when one attempts to classify a given company into one of the different groups. For example, ARM primarily provides semiconductor intellectual property, but increasingly provides the design tools to accompany the IP. For the purpose of this study, companies are classified according to their core business.
- 4.7.3 Figure 4.9 shows how the rapid growth in the fabless sub-sector is fuelling the growth in the total independent design sector. Sector turnover in 2004 was roughly equal across the three sub-sectors. With the rapid growth of the fabless sector, it is thought that this business model will soon account for the majority of the revenue attributable to the IDE sector serving the electronics industry. It is important to note that the compound annual growth rate of the fabless sector may be inflated relative to the other sectors, due to the low starting base in 2000.
- 4.7.4 The persistent differential growth rates of the different sub-sectors underlie a marked change in the division of revenue generated by the different players in the independent design engineering part of the electronics innovation system. Figure 4.10 shows that an increasing share of the total turnover of the IDE sector in the UK is being generated by the fabless sector. This raises the question whether the fabless business model is emerging as dominant.

Figure 4.9 Evolution of turnover of the three sub-sectors and the IDE sector as a whole over the period 2000-2004.

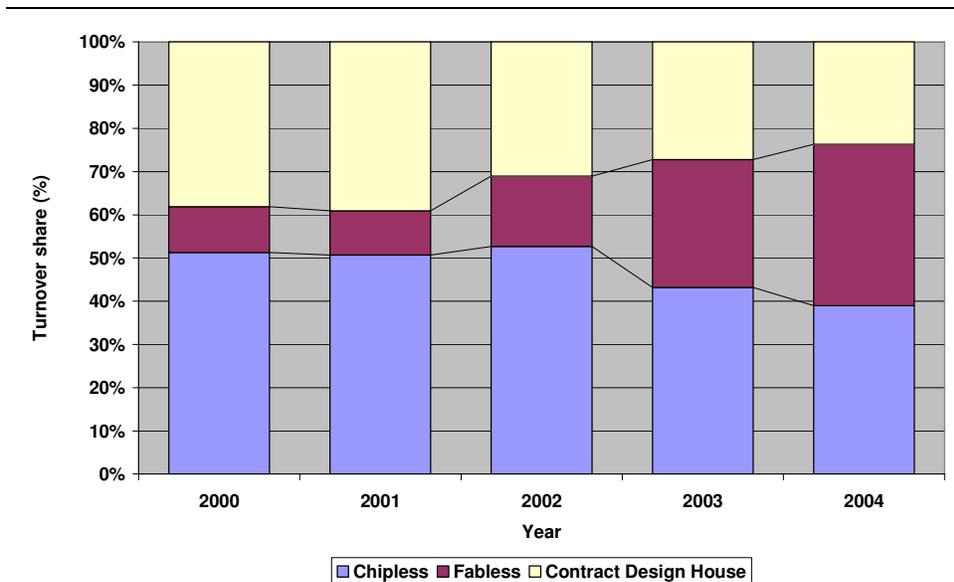


Current prices, sample estimates

Note: contract design house turnover *excludes* estimated turnover from freelance design engineers – the distribution of turnover given in this graph therefore differs from that given in 4.2.1.

Source: PACEC analysis, ORBIS

Figure 4.10 Distribution of turnover of the UK IDE sector over the period 2000-2004.



Current prices, sample estimate

Source: PACEC analysis, ORBIS

5 The performance of the UK electronics design engineering sector

5.1 Introduction

5.1.1 This chapter examines the productivity, profitability and efficiency performance of the sector and how it has evolved over the period 2000-2004. It first discusses the conceptual and practical issues associated with measuring productivity in design-intensive sectors, outlining the methodology used and the data limitations. Evidence is provided to answer three fundamental questions: (i) how does the productivity performance of the UK sector compare globally; (ii) how do the three sub-sectors compare with each other; and (iii) what are the main determinants of productivity differences?

Productivity and efficiency: theoretical concepts

5.1.2 The performance of a firm can be defined in many ways. Two key concepts are *productivity* and *efficiency*. Although regarded as the same thing, they are related but different concepts. The difference can be highlighted using the concept of a production frontier. A production frontier depicts the feasible outputs which can be produced from given inputs for a given technology. For given inputs it indicates the maximum output that can be produced, and for a given output the minimum inputs required. A natural measure of productivity is therefore the ratio of outputs to inputs (Coelli et al., 2005). Technical efficiency is achieved when a firm is on the production frontier, and inefficiency is measured by the distance of a firm to the frontier.

5.1.3 Two concepts of efficiency are used in empirical studies: technical efficiency and cost efficiency. Technical efficiency uses a production function framework to measure the rate of transformation of physical inputs into outputs, i.e. it ignores cost information. Cost efficiency extends the analysis to incorporate input costs showing the minimum cost of achieving a given level of output.

Measuring productivity and efficiency: a three-pronged approach

5.1.4 This study analyses productivity at the sectoral level by calculating turnover per employee, Gross Value Added (GVA) per employee, and turnover as a share of labour costs. It also analyses productivity at the firm level. Companies are ranked using different econometric measures of productivity and efficiency, and the performance of each relative to the sector as a whole is analysed.

5.1.5 The relative productivity performance of IDE companies is assessed by applying an econometric methodology to company financial data for firms in the UK, Europe and the US. The econometric analysis is largely based on 'stochastic frontier analysis' (SFA)³⁶, and covers:

³⁶ The results from estimating the more traditional linear regression model were unsatisfactory. The need for a richer set of variables and larger sample are indicated.

- Company level differences in labour productivity and their determinants
- Technical efficiency differences based on an output orientated approach and stochastic production frontiers
- Cost efficiency differences based on an input orientated cost approach and a stochastic cost frontier.

- 5.1.6 The first approach provides an initial exploration of the data and its quality. This approach has been used extensively in the analysis of labour productivity differences, e.g. Harris (2003). Differences in relative labour productivity are plotted and tabulated across country and through time, and a simple econometric model is used to explain these differences. Further multivariate analysis regresses differences in labour productivity against total labour costs per employee, real GVA and a range of company and contextual variables. In a separate analysis, the determinants of total factor productivity are investigated, using Harris and Trainor (2005) procedures.
- 5.1.7 The second approach decomposes the error term into a stochastic and a technical efficiency component. A production function is estimated using a stochastic frontier methodology. This approach measures the differences in technical efficiency across companies and models the determinants of variations in measured efficiency using firm characteristics and contextual variables. The model is based on Battese and Coelli (1993), and has been tested widely in the literature (see Appendix B).
- 5.1.8 The third approach analyses cost efficiency using stochastic frontier analysis, taking into account technological constraints (the production function) and economic constraints (input prices). This is more onerous in data requirements, requiring not only data on output and input use but also input prices, total expenditure on inputs used, and potentially input cost shares (Altumbas et al., 2001). The measure of cost inefficiency is given by the ratio of minimum cost to actual cost.³⁷ Following the technical efficiency methodology, cost efficiency is measured across companies and its determinants explained using firm characteristics and contextual variables.³⁸
- 5.1.9 The final tools used in the analysis of productivity in this study are the case study interview programme and the postal survey of firms in the sector. These valuable tools permitted the exploration of qualitative determinants of productivity that were beyond the reach of any solely quantitative methodology. Combining these three approaches, namely the descriptive analysis, the econometric analysis and the case study and postal survey results will yield powerful insights into what is driving productivity in the sector and how the UK compares globally.
- 5.1.10 Box 1 and 2 set out some of the problems of measuring productivity in design engineering sector and how these are taken on board in the study.

³⁷ In theory this measure of cost inefficiency may be broken down into that due to input-orientated technical efficiency and that due to input allocative efficiency. However, such decomposition is not possible using the econometric methodology adopted here.

³⁸ Full details on the precise econometric methodology can be found in Appendix B.

Box 5.1 Problems of measuring productivity in the IDE sector

The measurement of productivity, defined as the ratio of the outputs of a production process³⁹ to the inputs of that process, and the quantification of its determinants is notoriously difficult in service-based sectors such as design engineering. In manufacturing industries, productivity measures are typically derived by using hours of labour as a proxy for labour inputs, a measure of capital inputs is constructed from investment flows. Output tends to be measured as Gross Output or Gross Value Added per employee. Such measures implicitly assume that inputs and outputs are homogeneous (i.e. each unit of labour is identical; each unit of capital is identical; and each unit of output is identical).

In the case of design engineering sector the inputs and outputs of design engineering processes are typically very heterogeneous and not always 'tangible'. Professional knowledge and intellectual property inputs vary among professionals within and between firms depending on intelligence, education, experience or training. Outputs and their quality will vary by customer. It is not easy to find additional measures to capture these differences in quality. Secondly, traditional measures do not account for the heterogeneity inherent in these inputs and outputs.

Secondly, standard measures of productivity were designed for industries in which the customer had little or no involvement⁴⁰ (called *closed systems* (Grönroos and Ojasalo, 2000)). By contrast, design activity typically involves frequent close interaction with customers and their involvement in the production process (an *open system*). Customer involvement can have large (unmeasured) effects on the productivity of the design process and the quality of output, and can vary both between projects within a company and between companies (Nachum, 1999)

³⁹ The term 'production process' is used here to mean the processes by which inputs are combined to create the output (i.e. the service creation process, manufacturing process etc.)

⁴⁰ This is changing with the advent of CAD/CAM systems, and the use of ICT technology which increasingly links the customer with the manufacturer.

Box 5.2: Accounting for the limitations of productivity measures

These problems mean that it is not always possible to uncover the true drivers of productivity using data analysis alone. Methods for overcoming the limitations of traditional measures of labour inputs, physical and human capital inputs and outputs (e.g. Nachum (1999) and Grönroos and Ojasalo (2000)) require more data than is available in standard company accounts databases (e.g. FAME, ORBIS). This study has therefore focused on the traditional measures of productivity (turnover per employee, gross value added per employee etc.), and supplemented it with other qualitative investigations, through background research of trade literature, academic journals and company annual reports, case study interviews and the postal survey.

Labour input

Labour is the crucial input in the design services sector, but unmeasured variations in its quality undermine productivity measurement. It is not possible to measure the quality of labour directly, but wages are commonly used as a proxy.⁴¹ The 'cost of employees' (the combined wage bill) reflects both the level of education and the experience of employees, which are thought to be the major determinants of quality differences.

Physical capital input

The provision of design services to the electronics industry is increasingly physical capital-intensive, particularly office space and Information and Communications Technology (ICT) equipment. One reason for this is the high degree of geographically dispersed collaboration in the electronics industry. In this project, the measure of physical capital is based on annual investment in capital equipment.

⁴¹ The validity of this proxy is weakened by reputation effects which let firms attract higher quality people for the same wages. The 'cost of employees' should exclude directors' remuneration, to prevent different ownership structures e.g. partnerships from influencing results, (Nachum, 1999).

Definition of variables

- 5.1.11 Table 5.1 provides a list and definition of the variables used in the analyses. The table also sets out the actual variable selected from the ORBIS financial database, the database on which the analysis was based.

Table 5.1 Definition of variables

Variable	Definition	Description of variable*
Y	Turnover	Operating revenue/turnover
L	Number of employees	Employees
wL	Total wage bill	Costs of employees
π	Profits	Operating profit/loss (=Earnings before interest and tax)
TC	Total costs	Turnover minus Profits
TA	Total assets	Fixed assets + current assets
FA	Fixed assets	Fixed assets
CA	Current assets	Current assets

*: As defined by the ORBIS financial database

Measures of productivity

- 5.1.12 Despite the limitations of the traditional measures of productivity, namely turnover per employee, outlined above, it is still instructive to analyse this measure and can provide useful information regarding the productivity of service companies. Data limitations may also limit the power of other measures and it may therefore be necessary to revert to analysing such traditional measures. The equation used is:

$$\text{Productivity} = \frac{\text{Turnover}}{\text{Employees}} \left(= \frac{Y}{L} \right)$$

- 5.1.13 This report also considers the gross value added (GVA) per employee as a measure of productivity. This measure provides some indication of the extent to which the inputs are able to add value in creating the output. The equation used is:

$$\text{Productivity} = \frac{\text{GVA}}{\text{Employees}} = \frac{\text{Profits} + \text{labour costs}}{\text{Employees}} \left(= \frac{\pi + wL}{L} \right)$$

- 5.1.14 Lastly, given the importance of human capital in the IDE sector, this study considers the amount of turnover generated by each unit of labour costs as a proxy for productivity. The equation used is:

$$\text{Productivity} = \frac{\text{Turnover}}{\text{Labour costs}} \left(= \frac{Y}{wL} \right)$$

5.2 The database of design engineering companies

Database construction

5.2.1 There are no official data for the IDE sector. In the UK the IDE sector is supposed to be primarily classified in the Standard Industrial Classification code 74.2. This includes a number of services such as architectural activities, engineering and design activities for the construction and civil engineering sectors and geological and geodetic surveying activities not relevant to this study. In the United States similar classification problems exist: the US SIC 87.11 covers engineering services but excludes selected R&D services pertinent to this study. A number of IDE companies often choose the same SIC codes as their customers. This means that it is not possible to even focus a search for IDE companies within one SIC code – any search necessitates scanning many different codes. Therefore, for such a sector, the SIC codes provide little benefit for any sector-based analysis.

5.2.2 As a result it was decided to build a data base specific to the requirements of the study. Although there is some overlap between design engineering companies providing services to the automotive and electronics industries, two separate company data bases were assembled for the empirical analysis. For each of these segments, companies were identified from a wide variety of sources, including previous studies, trade associations and DTI working groups, such as the Design Engineering Group of the Society of Motor Manufacturers and Traders (SMMT).

5.2.3 The financial data for the sample of companies identified was obtained from the ORBIS database produced by Bureau van Dijk, which claims to be internationally comparable. All financial data (except the capital variables) have been deflated using the consumer price index (CPI), while capital data were deflated using an implicit price deflator based on capital prices. All financial data quoted in currencies other than British pounds were converted into pounds sterling at the 2004 exchange rate. Companies were included in the sample if their data quality satisfies two main criteria:

- Company has data for the required variables for the whole period 2000-2004. The sample of companies satisfying this criterion is referred to as the “*constant cohort*”.
- Company has data for part of the period 2000-2004 *and* was incorporated after 1998. The sample of companies satisfying this criterion is referred to as the “*new cohort*”.

The second of these criteria is to ensure that companies that enter the sample during the period being considered are *new* companies and not companies that, for whatever reason, begin to report data. It was thought that the inclusion of companies that simply started reporting data would affect the robustness of the analysis.

Table 5.2 Number of IDE companies identified in the UK, Europe and the US.

Sector	Number of companies			
	UK	Europe	US	Total
Automotive	52	35	95	182
Chipless	42	41	18	101
Contract design house	116	101	3	220
Fabless	36	86	142	264
Total	246	263	258	767

Coverage is *not* comprehensive for Europe and the US.
Source: ORBIS

- 5.2.4 The final database identified 767 IDE companies across the UK, Europe and the US, 246 of which were in the UK (Table 5.2). Coverage across Europe and the US was not meant to be comprehensive, but rather provide the potential for comparisons across different regions.
- 5.2.5 The lack of a design engineering SIC meant that each company had to be checked (primarily through company websites on the Internet, other trade literature or direct contact with the company) to ensure that it was truly part of the IDE sector. The data for each company had to be checked due to problems encountered with the database (e.g. treatment of n.a. as numerically zero). Where possible, outliers were checked against company accounts obtained from alternative sources and trade literature.
- 5.2.6 Table 5.3 demonstrates the limitations in the data. Only 28% of companies identified were deemed to have sufficient data⁴² for meaningful analysis. The best coverage was in the automotive sector where 54% and 57% of UK and European companies respectively had sufficient data. Unsurprisingly, the smaller companies were more likely to have insufficient data, and therefore the results are potentially biased towards the larger companies.
- 5.2.7 The table highlights the lack of US data, with only 4% of companies having sufficient data. Most design engineering companies in the US are privately owned and not legally required to file publicly available financial information either at a local, state or federal level. This severely limits the potential for comparisons with equivalent US sectors.

⁴² Sufficient data is defined as a company having six key variables (turnover, employees, costs of employees, operating profit, fixed assets and current assets) for at least three years over the period 1996-2004).

Table 5.3 Number of companies with sufficient data to permit analyses and the share of the total companies identified (given in brackets)

Sector	Number of companies			
	UK	Europe	US	Total
Automotive	28 (54)	20 (57)	1 (1)	49 (27)
Chipless	6 (14)	7 (17)	3 (17)	16 (16)
Contract design house	23 (20)	29 (29)	0 (0)	52 (24)
Fabless	11 (31)	12 (14)	7 (5)	30 (11)
Total	68 (28)	68 (26)	11 (4)	147 (19)

Notes:

1. Sufficient data defined as a company having six key variables (turnover, employees, costs of employees, operating profit, fixed assets and current assets) for at least three years over the period 1996-2004
 2. Number in brackets is the share of companies with data in the total number of companies identified (%).
- Source: ORBIS, PACEC analysis

5.3 The productivity performance of the sector

5.3.1 This section provides an overview of the productivity of the UK IDE sector and its sub-sectors. It examines its evolution over the period 2000-2004 and explores how it compares to similar sectors in the United States and Europe. This section also investigates individual company performance relative to the sector, and how they rank according to a variety of productivity and related efficiency measures for the latest year, 2004. Finally, it analyses the factors underpinning the productivity results, using both econometric analysis and the survey research (based on both case studies and a postal survey of firms).

How has productivity in the UK independent design engineering sector evolved?

Table 5.4 Productivity measures for the UK IDE sector and sub-sectors for 2000 and 2004

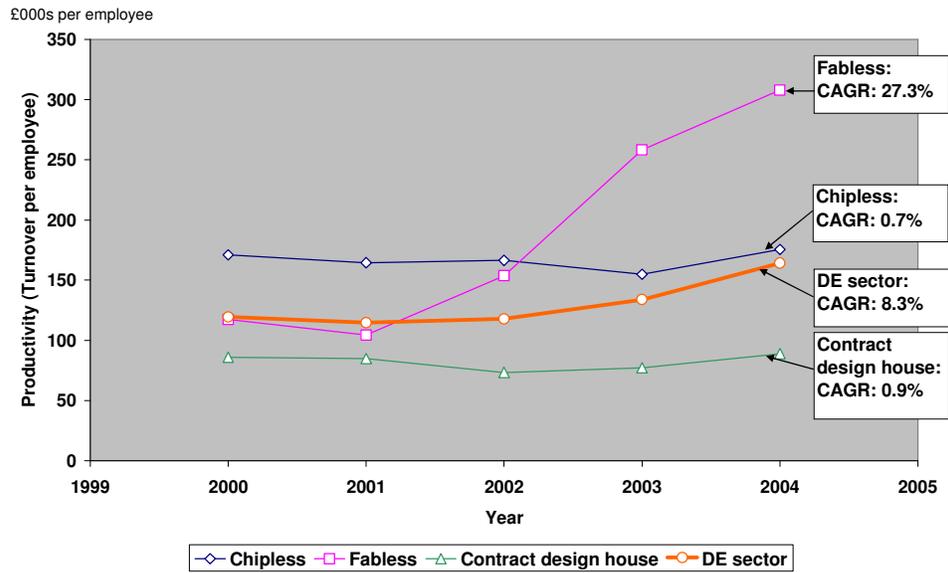
Sector	Turnover per employee (£000s per employee)			GVA per employee (£000s per employee)			Turnover as a share of labour costs (%)		
	2000	2004	CAGR (%)	2000	2004	CAGR (%)	2000	2004	CAGR (%)
IDE sector	120	164	8.3	45	61	8.2	257	323	6.0
Chipless	171	176	0.7	71	70	-0.5	330	328	-0.1
Fabless	117	308	27.3	-12	70	n.a.	315	720	23.0
Contract design house	86	89	0.9	37	50	7.8	191	171	-2.7

All measures are weighted averages, constant 2004 prices where appropriate). Compound annual growth rates have been calculated where possible and taken over the period 2000-2004 (% per annum)
Source: PACEC analysis, ORBIS

5.3.2 The design engineering sector in the UK generates approximately £164,000 of turnover per employee, with the fabless sector the most productive, followed by the chipless sector, then the contract design house sector. All three productivity measures indicate similar trends. The productivity of the more established sectors (contract design house and chipless) changed little over the period 2000-2004.⁴³ All three measures show the productivity of the fabless sub-sector increasing rapidly, which was the main factor behind the increased productivity of the sector over the period (see Figure 5.1 and Figure 5.2).

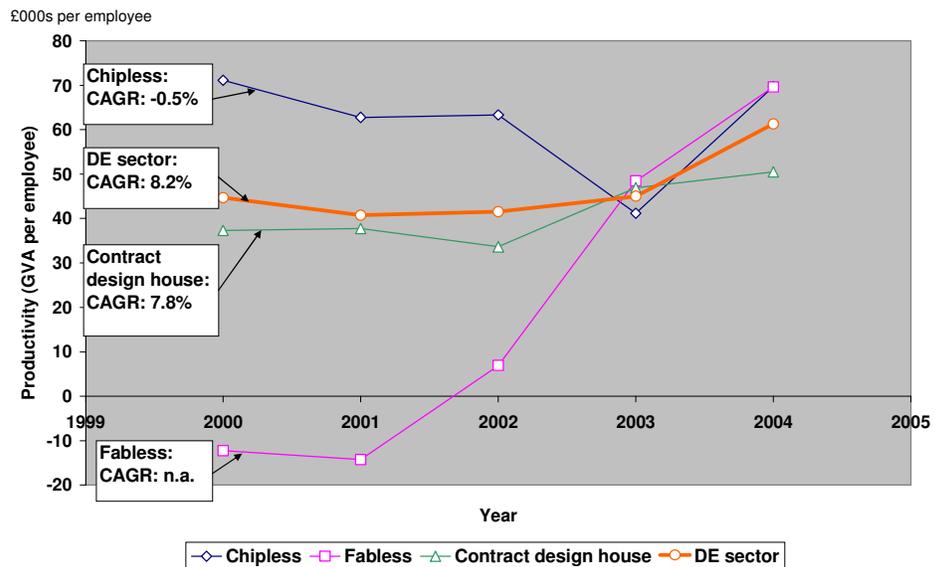
⁴³ With the exception of 2003 when the chipless sector witnessed a one-off decline in GVA per employee.

Figure 5.1 Evolution of productivity proxied by turnover per employee⁴⁴.



Constant 2004 prices, £000s per employee.
Compound annual growth rates (CAGR) taken over the period 2000-2004 (% per annum)
Source: PACEC analysis, ORBIS

Figure 5.2 Evolution of productivity proxied by GVA per employee.



Constant 2004 prices, £000s per employee.
Compound annual growth rates (CAGR) taken over the period 2000-2004 (% per annum)
Source: PACEC analysis, ORBIS

5.3.3 The productivity of the sector in earlier years is thought to have been affected by the severe downturn in the electronics industry in 2001, rather than a decrease in the ability of companies to effectively combine inputs to create output. In a highly cyclical industry such as the semiconductor industry, companies requiring a highly skilled

⁴⁴ The evolution of turnover per unit labour costs is similar to that of turnover per employee over the period and has therefore not been presented in this report.

workforce tend to 'ride out the storm' by hoarding labour. The marked decrease in GVA per employee in the chipless sector in 2003 was due to a fall in profits across many companies in the sub-sector (including ARM, ARC and TTPCom). The fall in GVA per employee of ARM was due to lower revenues in 2003, rather than higher costs. This has been attributed to lower demand for semiconductor IP, caused by the slowdown in the semiconductor industry, and resulting in significant tightening of budgets by customers (ARM, 2003).

5.3.4 The productivity of the UK electronics design engineering sector increased according to all measures of productivity considered, with a compound annual growth rate over the period 2000-2004 of approximately 8% per annum (Table 5.4, Figure 5.1). As with the growth in the size of the sector, productivity growth is being driven by increased productivity in the fabless sub-sector, while productivity in the chipless sector has remained approximately constant. This result is robust for the commodity-based sectors (fabless and chipless) across the different measures of productivity⁴⁵. However, this is not the case for contract design houses, where both turnover per employee and turnover per unit labour costs suggest that the productivity of the sub-sector has either remained unchanged or even slightly decreased, although the GVA per employee measure suggests that it has increased substantially⁴⁶. Understanding which productivity measure is most appropriate for this sub-sector is, therefore, crucial for analysing the dynamics of the sub-sector and company level performance.

5.3.5 One explanation lies in the way consultancies sell their design capabilities. Contract design houses typically sell fee-days to particular customers on specific projects, so that their revenue is a function of the fee-rate, the number of fee-days sold, and the utilisation rate of the consultants. Assuming that fee-days and utilisation rate are approximately constant for a given company⁴⁷ with a given set of human and physical capital resources, the fee-rate is the sole method for increasing revenue. The case study interviews suggest that contract design houses in the electronics innovation system are price takers and cannot significantly affect the fee-rate, thus fixing this variable too. Turnover per employee is, therefore, a poor measure of productivity as it does not reflect the ability of the contract design house to improve its ability to combine inputs to create output. Gross value added per employee provides a more accurate proxy for productivity in the contract design house sub-sector. Table 5.4 shows that the contract design house sub-sector increased the amount of value added generated by each employee over the period 2000-2004.

⁴⁵ The correlation between the different productivity measures is near to unity for both the fabless and chipless sectors (the commodity based sectors) suggesting that the movement in productivity can be inferred by looking at any of the three measures.

⁴⁶ The correlation between the turnover per employee and GVA per employee was approximately 0.4 suggesting a fairly weak relationship between the movement in the two measures. The correlation between GVA per employee and turnover per unit labour costs was -0.45.

⁴⁷ While these can vary significantly in the short term, it is believed that in the medium term, they are approximately constant.

Digging deeper: how do individual companies perform?

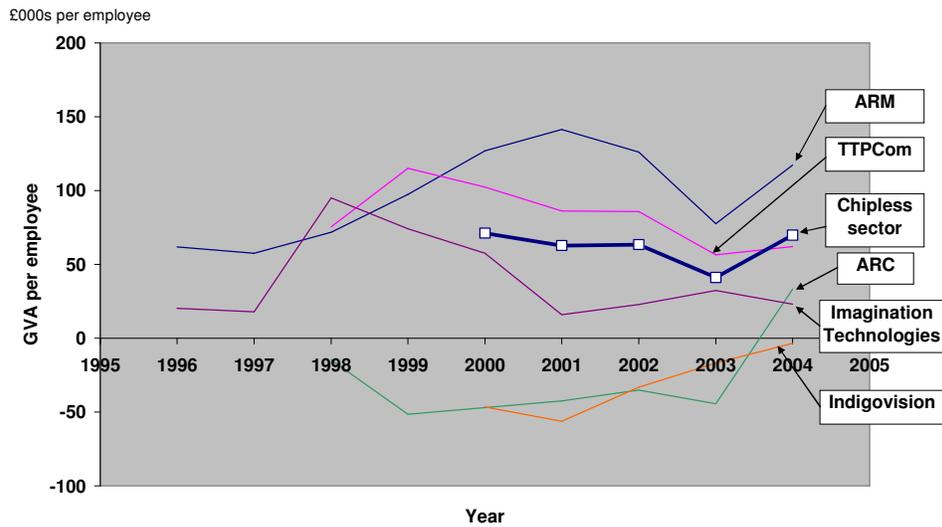
- 5.3.6 Each sub-sector is dominated by a small number of companies which are likely to influence greatly the sector's evolution of aggregate productivity. Figure 5.3 to Figure 5.7 provide the analysis of evolution of productivity at the company level.
- 5.3.7 ARM's position as global market leader is reflected in its high productivity compared to the rest of the UK chipless sector, producing a GVA per employee of approximately £117,000 per employee in 2004, almost twice that of the company with the second highest productivity in the sector, TTPCom. The evolution of the productivity of ARM also shows that it was affected by the recession in the wider electronics industry, and experienced a decrease in GVA per employee from 2001-2003. Most companies in the sector increased productivity between 2003 and 2004.
- 5.3.8 ARC, a spin off from an OEM in 1998, experienced the fastest growth in productivity between 2003 and 2004. It has clearly emerged from its start-up phase and is 'catching up' to the sector. ARC developed a strong position in its market niche, focusing on the intellectual property of configurable cores that can be used in many embedded applications, a market that is growing much more rapidly than its non-configurable counterparts. Semico Research Corp. predict that total processor cores sales will approach 4 billion by 2010, up from 2.5 billion today, of which approximately 25% will be configurable, up from 8% today⁴⁸. Some industry experts believe that Semico Research underestimate the forecasted 2010 market size with expected growth much higher.
- 5.3.9 CSR, the leading UK fabless company, and the global leader in Bluetooth technology, had the highest productivity in 2004, not only in the fabless sector but also in the whole UK design engineering sector, with a turnover of about £194,000 per employee. This is over twice that of Frontier Silicon, and about three-and-a-half times that of Oxford Semiconductor.
- 5.3.10 Frontier Silicon has been described as one of the emerging success stories in the UK fabless sector. Its negative gross value added per employee (Figure 5.4) is due to the fact that Frontier Silicon is still in its start-up phase and producing negative profits. If one looks at another measure of productivity, turnover per employee, it is the second highest in the fabless sector, with £480,000 per employee.
- 5.3.11 The above discussion demonstrates the large difference between the productivity (GVA per employee) of the sector leaders and 'followers' in these design-product⁴⁹ based sectors. The picture is different in the contract design house sector, which is much less concentrated. The large technology consultancies appear to have broadly similar levels of productivity. Figure 5.5 to Figure 5.7 show that Cambridge Consultants, The Technology Partnership and Sharp Laboratories (wholly owned by

⁴⁸ EETimes (2006) "Configurable processors on the rise, speakers say", published in EETimes on 31st October 2006.

⁴⁹ The study makes a distinction between the two sub-sectors that are focused on providing design capability through the sale and marketing (though not manufacture) of products, and those companies that provide it through consultancy-based services. The former category of sub-sectors are referred to as 'design-product' sub-sectors (fabless and chipless) and compared with the 'design-service' sub-sector (contract design houses)

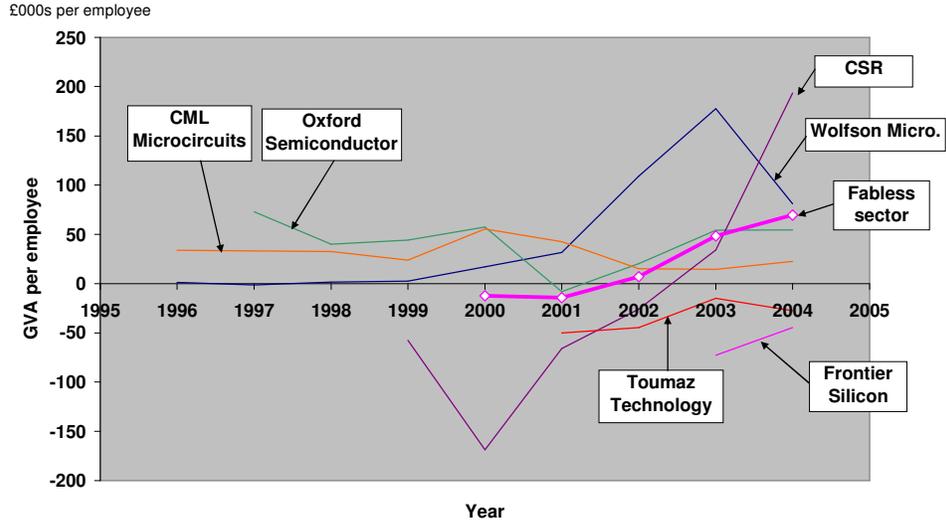
Sharp, their main 'customer' for contract design services) are consistently more productive than the sector average. Plextek and Generics appear to have suffered from the recession in the electronics industry, with productivity falling from above the sector average before 2001, to below it. During this period it is thought that the contract design house sector experienced a decline in demand. Given the difficulty in recruiting highly skilled and business minded engineers, most of the larger consultancies chose to hoard labour rather than downsize. Figure 5.5 shows that Generics recovered from their drop in productivity by 2004, while Plextek productivity showed only a very gradual increase after the sharp decline in 2001.

Figure 5.3 Evolution of productivity (GVA per employee) for the chipless sector.



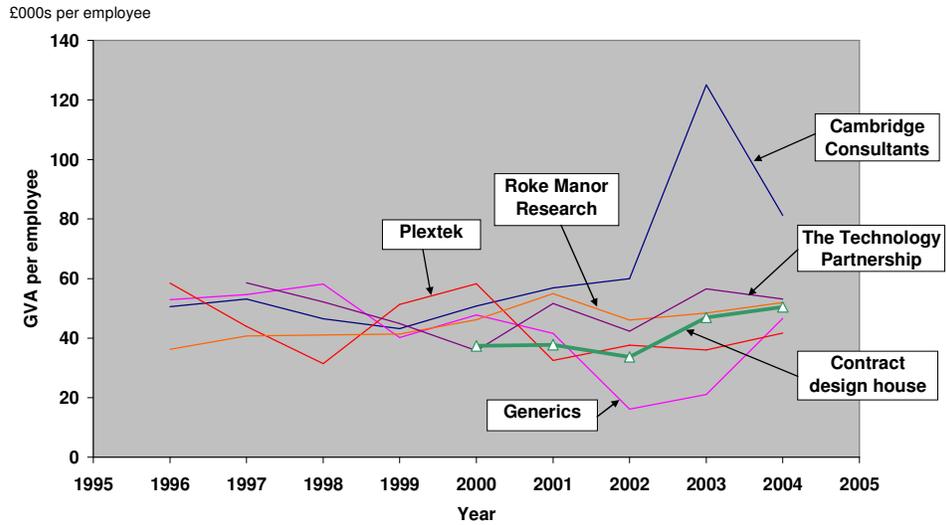
£000s per employee, constant 2004 prices
 Source: PACEC analysis, ORBIS

Figure 5.4 Evolution of productivity (GVA per employee) for the fables sector.



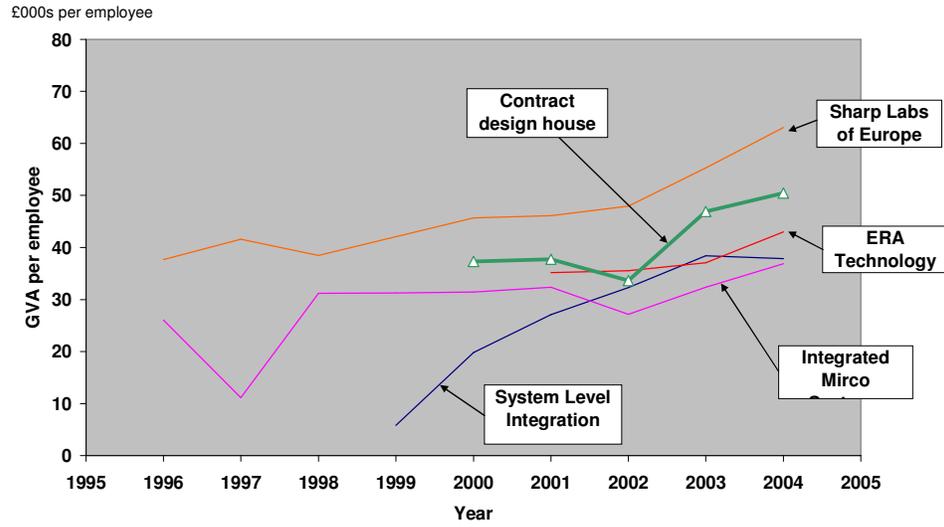
£000s per employee, constant 2004 prices
Source: PACEC analysis, ORBIS

Figure 5.5 Evolution of productivity (GVA per employee) for the contract design house sector. Selected companies in the Cambridge cluster and Roke Manor Research.



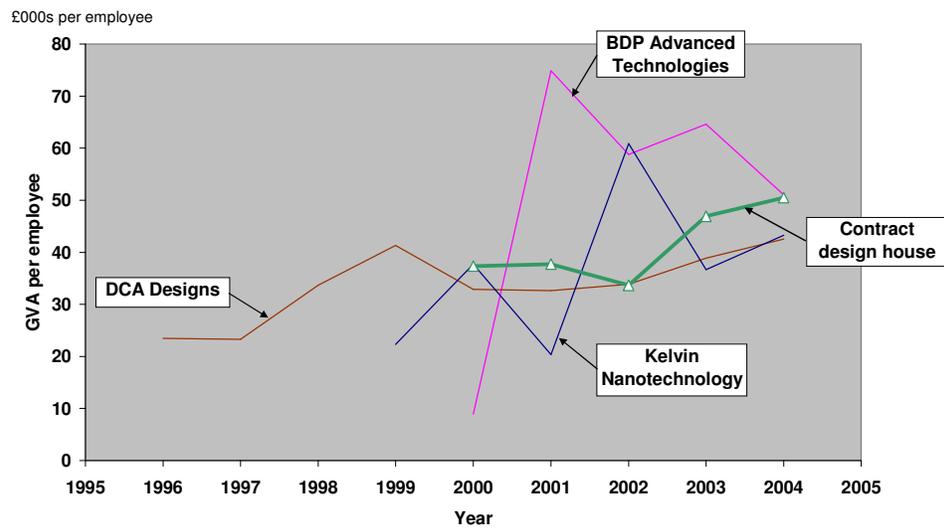
£000s per employee, constant 2004 prices
Source: PACEC analysis, ORBIS

Figure 5.6 Evolution of productivity (GVA per employee) for the contract design house sector. Selected companies.



£000s per employee, constant 2004 prices
Source: PACEC analysis, ORBIS

Figure 5.7 Evolution of productivity (GVA per employee) for the contract design house sector. Selected companies.

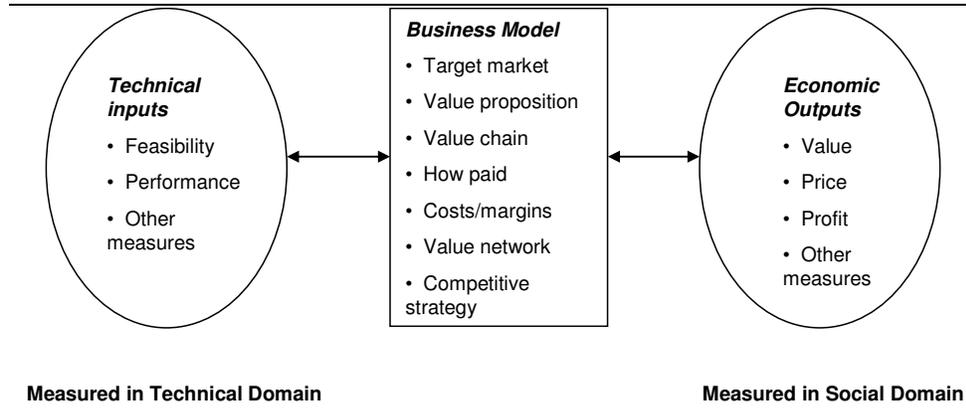


£000s per employee, constant 2004 prices
Source: PACEC analysis, ORBIS

5.3.12 A second company-level analysis of the productivity performance of the IDE sector was carried out, based on examining those companies which generated more value added per employee compared with the average company for a given turnover per employee.

5.3.13 The success of a company can be seen as the effectiveness of the particular business model, the conduit through which companies convert technological potential into economic value (Chesbrough, 2003). This is illustrated in Figure 5.8.

Figure 5.8 Business model as a mapping between the technical and social domains



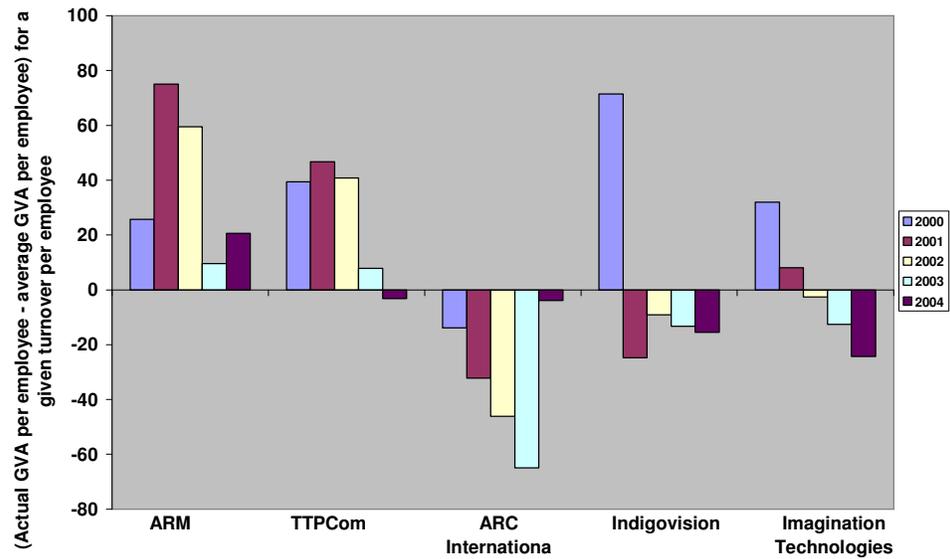
Source: Chesbrough (2003:69)

5.3.14 Chesbrough (2003:64) defines a business model as having six functions:

- 1 To articulate the 'value proposition' (the value created for users)
- 2 To identify a market segment (the users to whom the technology is useful and the purpose for which it will be used)
- 3 To define the structure of the value chain required to create and distribute the product, and determine the complementary assets needed to support the firm's position in this chain
- 4 To specify the revenue generation mechanism(s) for the firm, and estimate the cost structure and target margins of producing the product
- 5 To describe the position of the firm within the value network linking suppliers and customers, including identification of potential complementary firms and competitors
- 6 To formulate the competitive strategy by which the firm will gain and maintain advantage over its rivals.

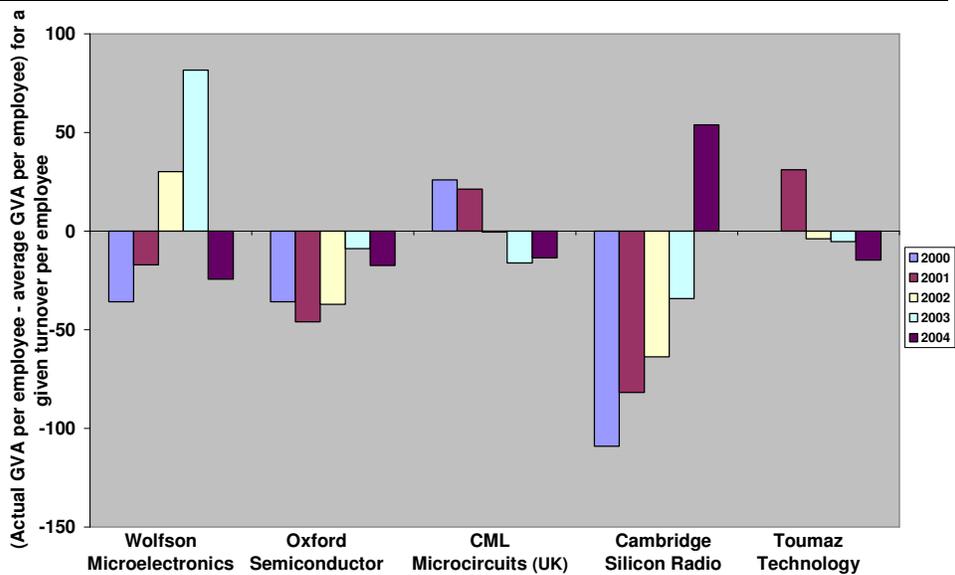
An above-average company will outperform the average company along one or more of these dimensions.

Figure 5.9 Productivity performance of firms relative to the sectoral average over the period 2000-2004 – chipless companies



Source: ORBIS, PACEC analysis
 Values estimated from the residuals of an OLS regression of GVA per employee on turnover per employee for each year 2000-2004.
 A positive value indicates productivity (GVA per employee) above that of the sectoral average

Figure 5.10 Productivity performance of firms relative to the sectoral average over the period 2000-2004 – fabless companies



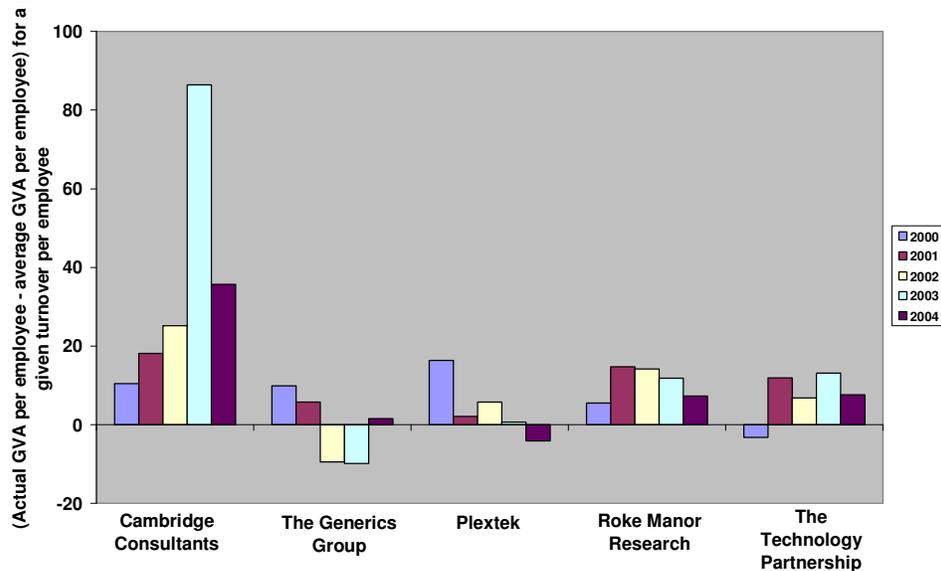
Source: ORBIS, PACEC analysis
 Values estimated from the residuals of an OLS regression of GVA per employee on turnover per employee for each year 2000-2004.
 A positive value indicates productivity (GVA per employee) above that of the sectoral average

5.3.15 The analysis is presented in Figure 5.9 to Figure 5.12. The most successful chipless company (Figure 5.9) is ARM, with TTPCom also showing above average productivity

performance for all years except 2004. The growing strength of ARC's position in the market is shown by its marked improvement between 2003 and 2004.

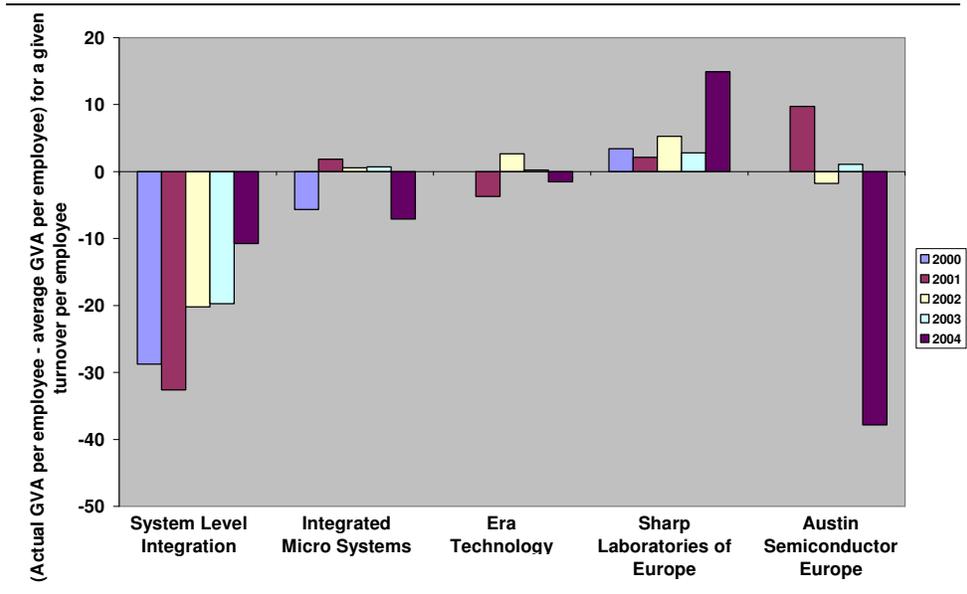
5.3.16 The analysis of fabless companies shows the emergence of Cambridge Silicon Radio and Wolfson Microelectronics from their start-up phases (Wolfson Microelectronics experienced a drop in profits in 2004 which have subsequently rebounded, with profits doubling between 2004 and 2005). Toumaz Technology, a small start-up spun-off from Imperial College, London in 2000, underperformed relative to the sector average for most years. Oxford Semiconductor produced comparable GVA per employee in 2004 to Wolfson Microelectronics and Cambridge Silicon Radio, but significantly less on a turnover per employee basis.

Figure 5.11 Productivity performance of firms relative to the sectoral average over the period 2000-2004 – contract design houses in the Cambridge cluster and Roke Manor Research



Source: ORBIS, PACEC analysis
 Values estimated from the residuals of an OLS regression of GVA per employee on turnover per employee for each year 2000-2004.
 A positive value indicates productivity (GVA per employee) above that of the sectoral average

Figure 5.12 Productivity performance of firms relative to the sectoral average over the period 2000-2004 – selected contract design houses



Source: ORBIS, PACEC analysis
 Values estimated from the residuals of an OLS regression of GVA per employee on turnover per employee for each year 2000-2004.
 A positive value indicates productivity (GVA per employee) above that of the sectoral average

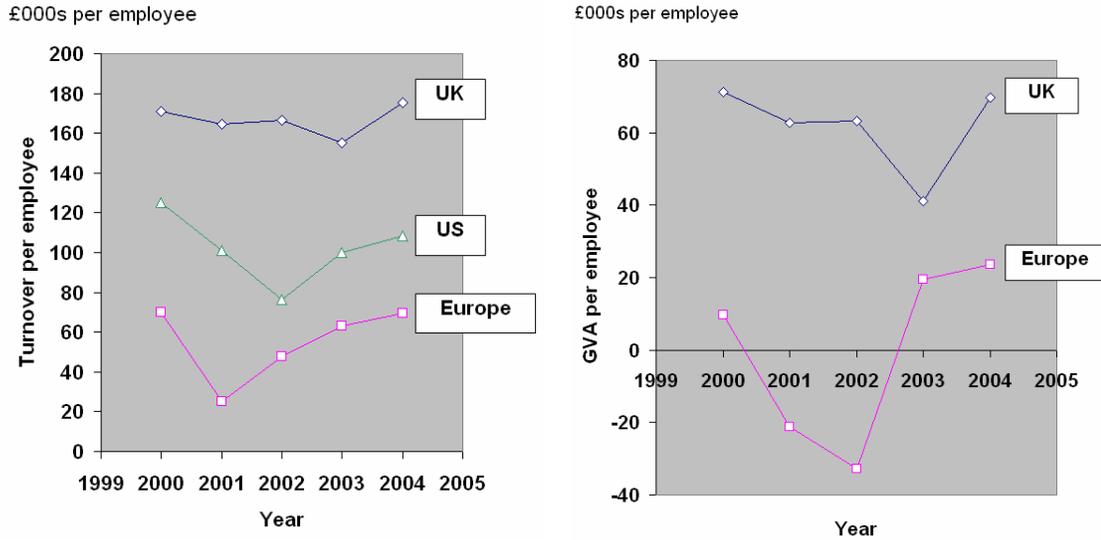
5.3.17 Cambridge Consultants, The Technology Partnership and Roke Manor Research outperformed the contract design house sub-sector over much of the period, while Generics and Plextek had mixed fortunes, thus confirming the earlier findings.

How does the productivity performance of the UK independent design engineering sector compare internationally?

5.3.18 Analysis of the global market penetration of the three sub-sectors has shown firstly the domination of the UK chipless sector and secondly that the fabless sector has only captured a very small proportion of total global fabless revenue. Nonetheless, selected companies are global leaders in their individual market niches.

5.3.19 This sub-section now compares the performance of the three sub-sectors with globally comparable sectors.

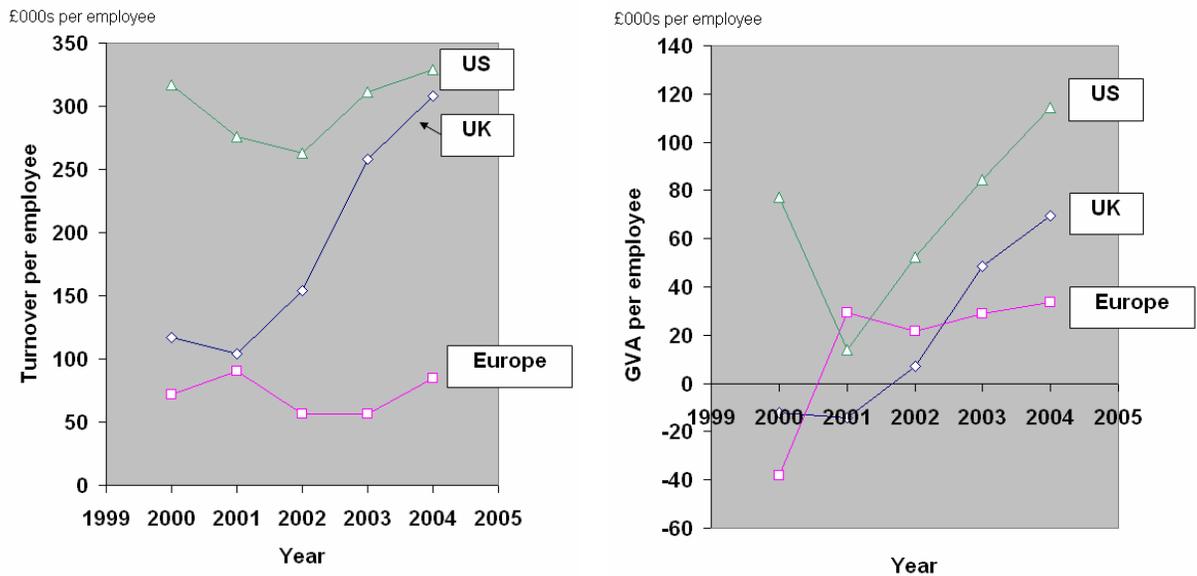
Figure 5.13 Productivity measures (turnover per employee, GVA per employee) for the chipless sub-sectors in the UK, Europe and the US.



£000s per employee, constant 2004 prices
Source: PACEC analysis, ORBIS

5.3.20 The UK chipless sub-sector was more productive than its US and European counterparts throughout 2000-2004, on the basis of turnover per employee, and more productive than Europe on the basis of GVA per employee, (see Figure 5.13). All regions appear to have suffered a reduction in productivity during the recession in the semiconductor industry, but have since recovered to pre-2001 levels.

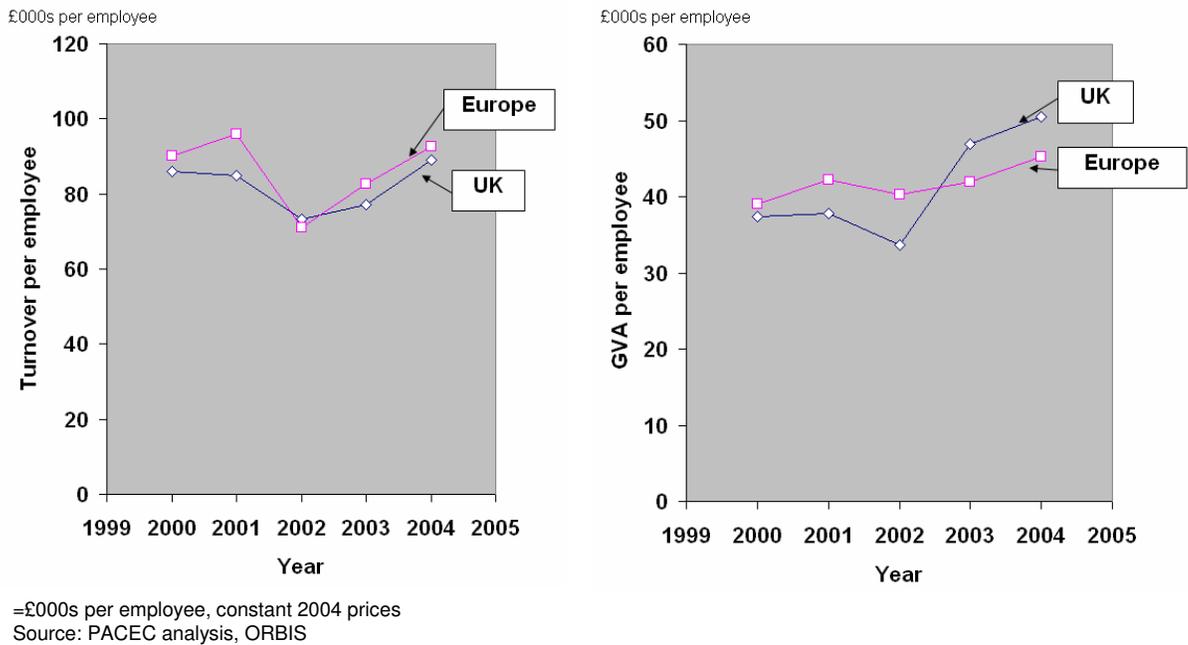
Figure 5.14 Productivity measures (turnover per employee, GVA per employee) for the fabless sub-sectors in the UK, Europe and the US.



£000s per employee, constant 2004 prices
Source: PACEC analysis, ORBIS

5.3.21 Figure 5.14 shows that the UK fabless sector has emerged from its infancy to contend with the US fabless sector in terms of productivity, even if not yet able to match the market penetration. The 'catching up' of the UK to the US is due to the rapidly increasing productivities of CSR, Frontier Silicon and Wolfson Microelectronics. The amount of value added per employee is also increasing, although such increase is also evident in the US. European fabless companies have yet to replicate the UK's success in increasing its productivity to near-US levels.

Figure 5.15 Productivity measures (turnover per employee, GVA per employee) for the contract design house sub-sectors in the UK, Europe and the US.



5.3.22 Data limitations mean that it is not possible to compare UK and European contract design houses with their US counterparts (US firms identified as contract design houses are privately held and not required to file financial data). The US samples for the fabless and chipless sub-sectors are, therefore, limited to publicly quoted companies. Nevertheless, the productivity of the UK contract design house sub-sector is comparable with that of European companies according to both measures of productivity. Figure 5.15 shows that the UK contract design house sub-sector now has a higher productivity performance than its European counterpart, unlike in the early part of the sample period.

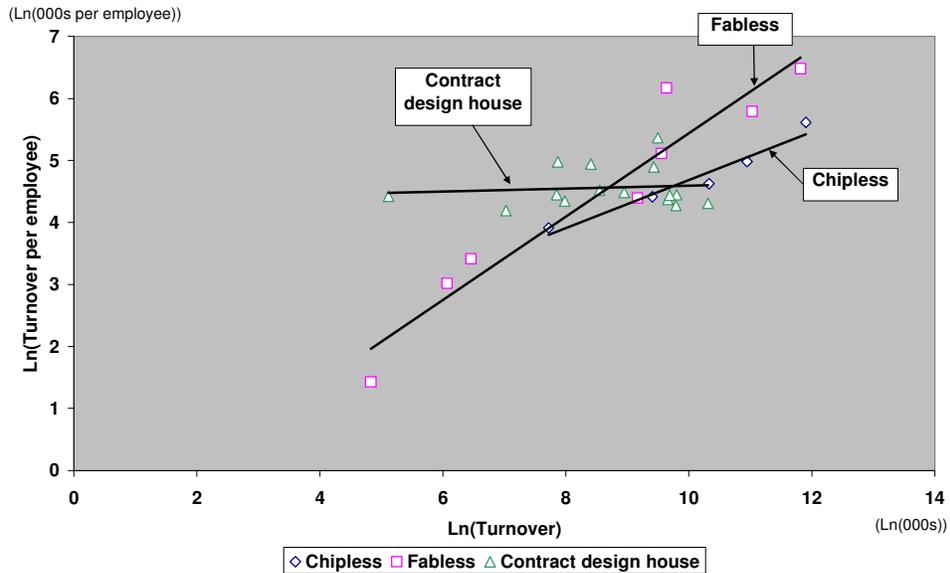
Does size matter?

5.3.23 Whether companies benefit from internal economies of scale is an important determinant of whether UK companies can compete with much larger global competitors.

5.3.24 Size is commonly measured by the number of employees or by turnover. Neither measure is perfect, as a firm that is large in terms of number of employees could be a

small player in the sector. Turnover is considered a better proxy for this study as the focus is on value creation.

Figure 5.16 Relationship between productivity (turnover per employee) and size (turnover) in 2004



Source: PACEC analysis, ORBIS

5.3.25 A clear relationship between size and productivity emerges for the chipless and fables sub-sectors when the natural log of size (turnover) is plotted against the natural log of productivity (turnover per employee) (see Figure 5.16). However, there is no relationship for the contract design house sub-sector.

5.3.26 The magnitude of the effect of size on productivity can be deduced using simple bivariate linear regression analyses, assuming a linear relationship between the natural log of size (turnover) and the natural log of productivity (turnover per employee) (as suggested by Figure 5.16):

$$\ln(\text{Productivity}) = \alpha + \beta \ln(\text{Size})$$

where α is a constant and β is the elasticity of productivity with respect to size. Running a simple bivariate linear regression using Ordinary Least Squares (OLS) techniques, gives the following results for the elasticity of productivity with respect to size for each year (where data permitted) during the period 2000-2004.

Table 5.5 Bivariate regression results analysing the effect of size (turnover) on productivity (turnover per employee).

		2000	2001	2002	2003	2004
Chipless*	β	0.51	0.58	0.63	0.55	0.39
	R^2	0.96	0.95	0.99	0.99	0.94
	t-ratio	n.a.	n.a.	n.a.	n.a.	n.a.
Fabless	β	n.a.	n.a.	n.a.	0.76	0.69
	R^2	n.a.	n.a.	n.a.	0.91	0.93
	t-ratio	n.a.	n.a.	n.a.	8.26	9.5
Contract design house	β	n.a.	0.21	0.09	0.05	0.02
	R^2	n.a.	0.2	0.04	0.01	0.01
	t-ratio	n.a.	1.81	0.71	0.33	0.36

Note *: The sample was too small for a regression analysis to be carried out for the chipless sub-sector. The elasticity, β , was simply calculated from the gradient of the graph using MS Excel.

Source: PACEC analysis, ORBIS

5.3.27 It is clear from Table 5.5 that there is a fairly strong relationship between size and productivity for both the fabless and chipless sub-sectors, but not for the contract design house sub-sector. Simple statistical tests of significance (using the standard t-test) reject the null hypothesis that the elasticity of productivity with respect to size is not significantly different from zero at all levels of significance for the fabless sector. However this null hypothesis cannot be rejected at even a 10% level of significance for the contract design house sub-sector.

5.3.28 The reasons why the chipless and fabless sub-sectors experience economies of scale likely lie in the way they sell their design capabilities. Both sectors generate revenues through the sale of design on a 'per unit' basis⁵⁰, while incurring substantial fixed and sunk costs.

Multivariate Analysis of Labour Productivity

5.3.29 As mentioned above we have attempted to analyse the variation of labour productivity by adopting a similar approach to Harris (2003). However, due to the lack of more detailed information for the firms in our sample, the results do not add significant information to the simple correlations and regressions described above. The only significant result is the positive and significant impact of firm size. We, therefore, do not report the regressions in this report, arguing that a robust econometric analysis would require a more complete list of firms' characteristics. The same applies to the automotive design engineering sector.

⁵⁰ Whether it be as a particular license for using intellectual property or from the physical sale of a chip

5.4 The efficiency of design engineering companies

- 5.4.1 The technical efficiency of individual firms was estimated using production functions and the stochastic frontier analysis techniques outlined above. Recall that the technical efficiency of a firm measures the firm's ability to combine inputs to create output, using a given technology *relative* to the maximum output that can be generated by that technology. The cost efficiency looks at the relative ability of companies to achieve the minimum cost of producing the level of output, subject to this given technology, with the distance from the optimal cost frontier providing an indication of the cost efficiency of the firm.
- 5.4.2 Stochastic frontier analysis was also used to investigate the determinants of the (in)efficiency of companies. This used an unbalanced panel of firms covering 1996-2004, with firm financial data taken from the ORBIS database, and contextual data gathered from a variety of sources (for UK companies only). Two samples were used; the first was UK companies only, while the second was cross-country.
- 5.4.3 The results are subject to a number of qualifications. Firstly, data constraints mean that the estimations are subject to specification problems. In particular, that constructed variables might not be perfect proxies for the theoretical ones, and that furthermore there are missing unmeasured variables. Secondly, the assumption that firms in the sample share the same technology and random factors is strong, particularly for such a diverse sector as design engineering.

Defining and interpreting the contextual variables

- 5.4.4 The contextual variables account for different spatial effects, including localisation economies, urbanisation economies, proximity to universities, clustering effects, geographical benefits (i.e. being in the right geographic region), and age effects. The variables, where appropriate, account for distance effects. For example, the benefit of a particular university will not only be felt in the immediate geographic location, but will also benefit surrounding areas.
- 5.4.5 Localisation economies: Firms locating within a region with a high concentration of companies in similar industries can benefit from intra-industry externalities. Marshall (1920) originally proposed that geographical concentrations of firms in industrial districts could generate thick labour markets, facilitating the co-location of subsidiary trades, knowledge diffusion and technological spillovers between firms, (see e.g. Fingleton et al.,2005).
- 5.4.6 Urbanisation economies: There is evidence that there are benefits from locating within areas with high concentrations of industries, regardless of sectoral composition. According to Jacobs (1969), companies located in densely populated areas can learn methods, techniques and ideas from each other.

- 5.4.7 Proximity to universities: Being close to good universities not only facilitates the diffusion of academic research into the commercial sphere, but also acts as a feedstock for skilled labour, two factors believed to be very important for this sector.
- 5.4.8 Age: Company age provides an indication of accumulated knowledge, which is considered to be very important in very creative, technologically challenging sectors. There are also benefits from learning by doing, a phenomenon first identified by Arrow (1962) who suggested that experience (the number of years spent doing a particular task) was directly related to improvements in productivity.
- 5.4.9 Geographical footprint: Different models of geographical operation might impact on a company's productivity or efficiency performance. While proximity to local markets and customers can ease information flows between firms, and help fine tune technical and commercial relationships, international dispersion might create staff management difficulties.

Table 5.6 Definitions of the contextual variables

Variable group	Variable name	Definition
Localisation economies	Science and technology professionals	Proximity of the company to the mass of science and technology professionals (S.O.C. 21 employees in employment) in different local authority districts, weighted for the effect of the distance of the company to each local authority district.
	Auto IDE employment	Proximity of the company to the mass of automotive design engineering employees in different local authority districts, weighted for the effect of the distance of the company to each local authority district.
	Elec IDE employment	Proximity of the company to the mass of electronics design engineering employees in different local authority districts, weighted for the effect of the distance of the company to each local authority district.
	Location quotient	Proximity of the company to concentrations of science and technology professionals (% of science and technology professionals in region relative to % of science and technology professionals nationally). Weighted for the effect of the distance of the company to each local authority district. Provides a relative measure of concentration
	Horizontal cluster	Proximity of the company to concentrations of science and technology professionals (difference between the actual number of science and technology professionals and the number of professionals that would be in a region if the region had a location quotient = 1 – i.e. if it had the national average). Weighted for the effect of the distance of the company to each local authority district. Takes account of not only the relative concentration, but also the absolute concentration.
	Auto IDE location quotient	Proximity of the company to automotive design engineering clusters (% of automotive design engineers in region relative to % of automotive design engineers nationally). Weighted for the effect of the distance of the company to each local authority district.
Elec IDE location quotient	Proximity of the company to electronics design engineering clusters (% of electronics design engineers in region relative to % of electronics design engineers nationally). Weighted for the effect of the distance of the company to each local authority district.	
Urbanisation economies	Total employment	Proximity of the company to economic masses (total employees in employment) in different local authority districts, weighted for the effect of the distance of the company to each local authority district. Provides an absolute measure of concentration.
Impact of universities	University	Proximity of the company to universities, weighted according to both the distance of the company to the university and the quality (Research Assessment Exercise) and size (size of science and technology departments) of the university (its 'impact').
Impact of innovation	Patents	Proximity of the company to innovative areas (extent of innovation proxied by the number of patents issued for each area), weighted for the effect of the distance of the company to each local authority district.
Geographical footprint	UK office	Company has an office in the UK
	US office	Company has an office in the USA
	EU office	Company has an office in Europe
	Far East office	Company has an office in the Far East
	Other office	Company has an office in another region of the world
	Non-UK office	UK-based company has an office outside the UK
	Age	Age of company = 2006 – Year of incorporation

Source: PACEC

Efficiency of the UK design engineering sector

Measures of technical and cost efficiency were calculated for the IDE sector as a whole, for each individual sub-sector and each company. However, lack of data on firms' input prices meant that the cost function could not be fully specified. While attempts at the estimation of the cost function were made, we concluded that the measures of cost efficiency (which is the systematic error term) not only captured the 'cost efficiency' of firms, but also the other cost inputs that could not be specified. For this reason, the cost efficiency analysis has been excluded from the main body of the report. They can be found in Appendix C.

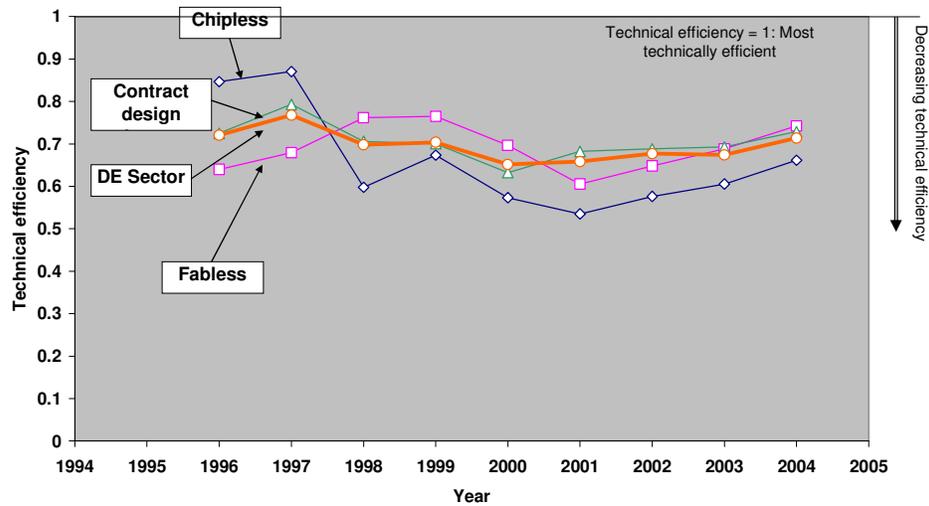
How has the efficiency of the UK design engineering sector changed?

5.4.10 The IDE sector as a whole exhibits some degree of cyclicity in the evolution of technical efficiency over the period 1996-2004. It became more technically inefficient

over the first half of the sample period before improving over the final half (see Figure 5.17). All the sub-sectors follow a similar pattern, albeit with varying degrees of volatility. The figure shows that the chipless sector, once the most technically efficient, is now the least. The contract design house sub-sector had a similar level of technical efficiency as the fabless sector at the end of the period.

5.4.11 The peaks and troughs in technical efficiency correspond roughly to the recession and recovery periods in the semiconductor and electronics industries. It is unsurprising that the efficiency of the sectors that serve these industries would increase and decrease in line with the expansion and contraction of their customers outsourcing budgets.

Figure 5.17 Evolution of the technical efficiency of the UK IDE sector and the sub-sectors over the period 1996-2004.



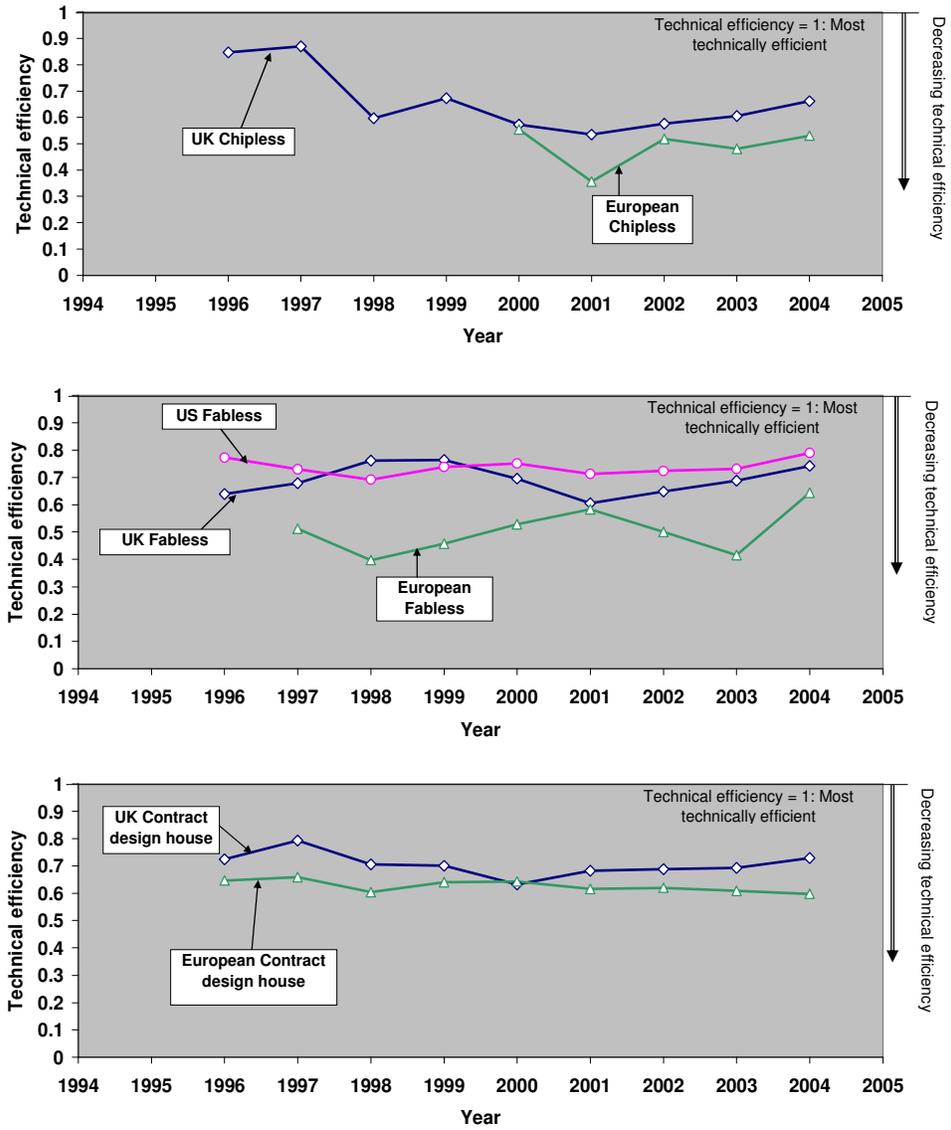
Maximum technical efficiency = 1
Source: PACEC analysis, ORBIS

How does efficiency in the UK compare with other global regions?

5.4.12 The US appears to be the most technically efficient of the three regions considered (see Figure 5.18). The UK follows, with all three sub-sectors more technically efficient than their European counterparts in 2004. It should be noted that data limitations meant that only publicly listed US-based companies could be analysed, so that estimates of US efficiency are likely to be biased upwards.⁵¹

⁵¹ Many of these larger US companies have design centres in the UK. For example, Broadcom, the second largest US fabless company has a number of design centres in the UK, recently acquiring the emerging Bristol based company, Element 14. The UK operations of these highly internationally distributed companies will therefore be contributing to their superior technical and cost efficiency.

Figure 5.18 Technical efficiency of the three sub-sectors of IDE in different global regions



Source: PACEC analysis, ORBIS

How efficient are UK companies?

5.4.13 At the company level, Cambridge Silicon Radio has the highest technical efficiency of the IDE sector sample analysed (see Table 5.7).⁵²

Table 5.7 Ranking of UK companies according to technical and cost efficiency, productivity (proxied by GVA per employee) and profitability.

Sub-sector	Company name	2004		2003	
		Technical efficiency	Technical efficiency ranking	Technical efficiency	Technical efficiency ranking
Chipless	ARM	0.89	2	0.88	2
	TTPCOM	0.84	8	0.82	9
	IMAGINATION TECHNOLOGIES	0.79	13	0.84	6
	INDIGOVISION	0.49	21	0.26	22
	ARC INTERNATIONAL	0.29	25	0.23	23
	Mean UK chipless	0.66	n.a.	0.61	n.a.
	Mean European chipless	0.53	n.a.	0.48	n.a.
Fabless	CAMBRIDGE SILICON RADIO	0.92	1	0.85	4
	WOLFSON MICROELECTRONICS	0.87	3	0.89	1
	OXFORD SEMICONDUCTOR	0.76	14	0.80	11
	CML MICROCIRCUITS (UK)	0.73	16	0.64	19
	TOUMAZ TECHNOLOGY	0.42	22	0.13	24
	Mean UK fabless	0.74	n.a.	0.69	n.a.
	Mean US fabless	0.79	n.a.	0.73	n.a.
Mean European fabless	0.64	n.a.	0.42	n.a.	
Contract design house	ROKE MANOR RESEARCH	0.86	4	0.87	3
	PLEXTEK	0.86	5	0.80	13
	AUSTIN SEMICONDUCTOR EUROPE	0.85	6	0.39	21
	SHARP LABORATORIES OF EUROPE	0.84	7	0.83	8
	INTEGRATED MICRO SYSTEMS	0.83	9	0.79	14
	THE GENERICS GROUP	0.82	10	0.76	16
	DCA DESIGN INTERNATIONAL	0.81	11	0.79	15
	THE TECHNOLOGY PARTNERSHIP	0.81	12	0.82	10
	SYSTEM LEVEL INTEGRATION	0.75	15	0.80	12
	AMINO COMMUNICATIONS	0.71	17	0.11	25
	BDP ADVANCED TECHNOLOGIES	0.68	18	0.83	7
	ERA TECHNOLOGY	0.68	19	0.66	18
	CAMBRIDGE CONSULTANTS	0.64	20	0.85	5
	KELVIN NANOTECHNOLOGY	0.40	23	0.72	17
	CELOXICA	0.38	24	0.40	20
Mean UK contract design house	0.73	n.a.	0.69	n.a.	
Mean European contract design house	0.60	n.a.	0.61	n.a.	

Source: PACEC analysis, ORBIS

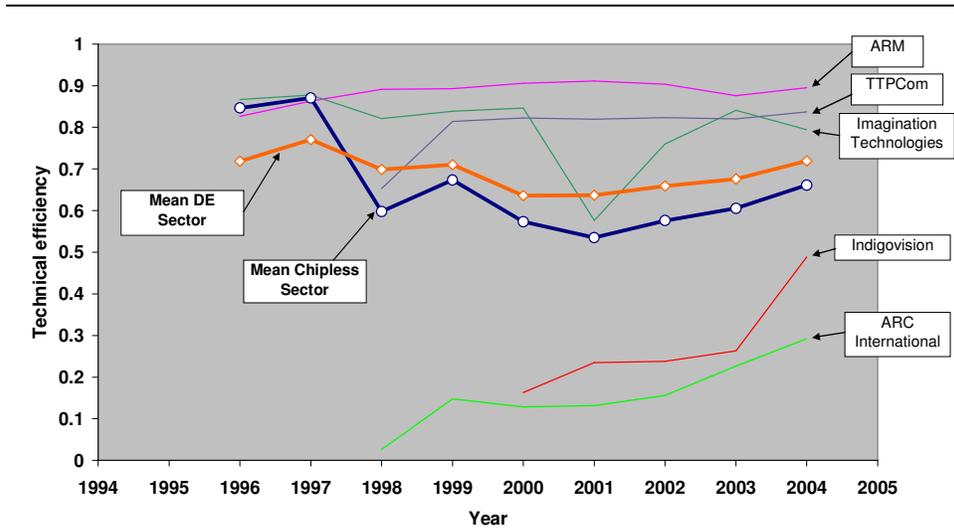
⁵² The results should be treated with caution as companies, even within the same sub-sector will be offering differentiated products. Comparisons should therefore be treated as tentative only.

- 5.4.14 ARM was the most technically efficient of the chipless companies in both 2003 and 2004. Cambridge Silicon Radio overtook Wolfson Microelectronics as the most technically efficient company in the nascent fabless sector. Roke Manor Research leads the contract design house sub-sector in technical efficiency.
- 5.4.15 The above results only provide evidence on the technical efficiency over a very short time period. Figure 5.19 to Figure 5.22 show the evolution of this measure of performance over the period 1996-2004. Of particular interest is the question of whether there are trends in the technical efficiency of successful start-up companies.
- 5.4.16 Figure 5.19 shows that ARM maintained its position as the most technically efficient company in the chipless sector. Unsurprisingly, the three companies in the global top ten of semiconductor intellectual property providers all have a technical efficiency higher than the average for the chipless sector and design engineering sector as a whole.
- 5.4.17 In both the fabless and chipless sectors (see Figure 5.19 and Figure 5.20), start-up companies begin with a very low technical efficiency. However, successful fabless start-ups quickly increase their technical efficiency to above the sector mean (evident with both Wolfson Microelectronics and Cambridge Silicon Radio). This appears not to be the case in the chipless sector, evidenced by the much slower growth in technical efficiency of ARC.
- 5.4.18 A company with low technical efficiency has low output per unit labour for a given capital per labour ratio. A low value of output per unit labour for a given capital-labour ratio might be due to (a) low sales for a given capital and labour employed, (b) the use of price discounts to overcome barriers at a particular stage of growth⁵³, and (c) significant differences in the technologies used across firms⁵⁴.

⁵³ The strategic use of price discounts to overcome barriers to entry into a market will be discussed in Chapter 6.

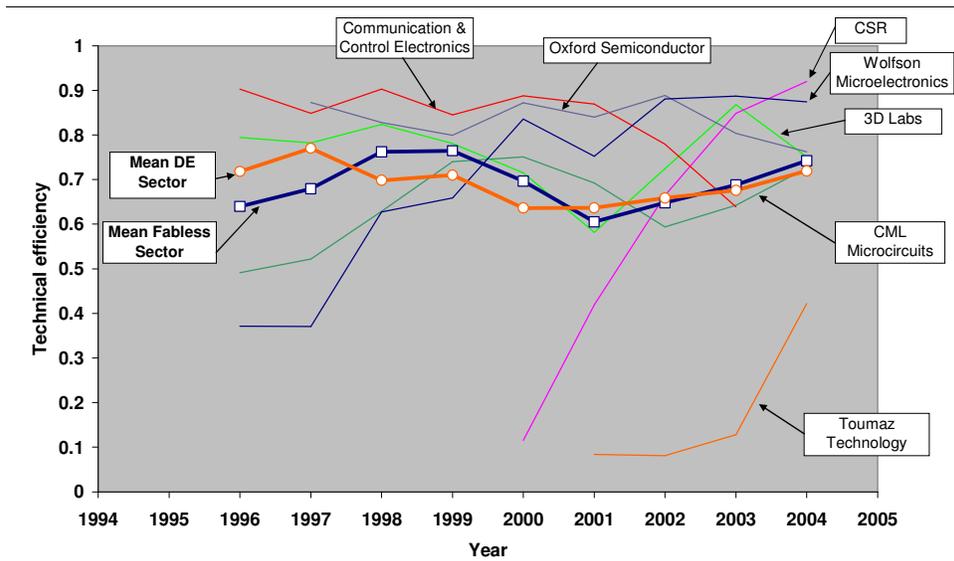
⁵⁴ If the technology facing the start-up is fundamentally different from that facing the incumbent, their production frontiers will differ and the true efficiency of the start-up may be comparable to the incumbent.

Figure 5.19 Evolution of technical efficiency of the UK chipless sector over the period 1996-2004.



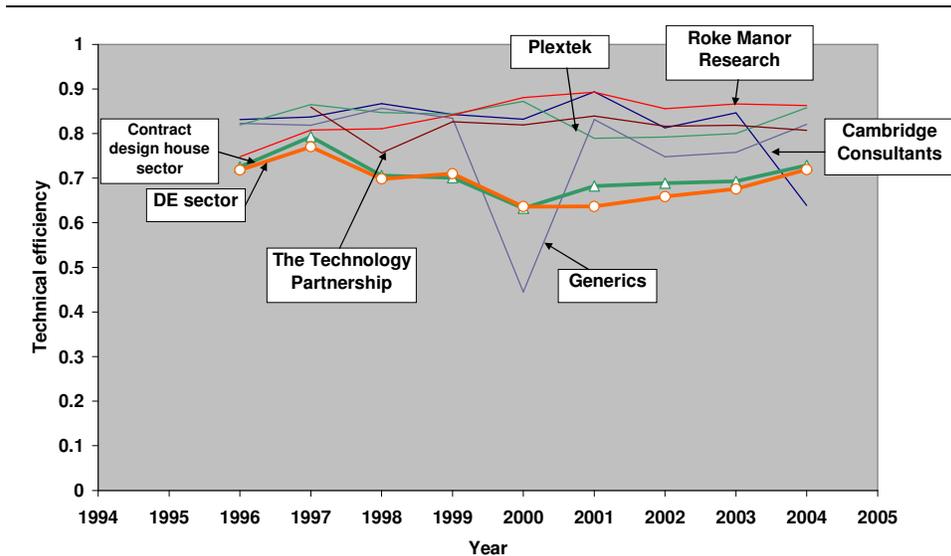
Source: PACEC analysis, ORBIS

Figure 5.20 Evolution of technical efficiency of the UK fabless sector over the period 1996-2004



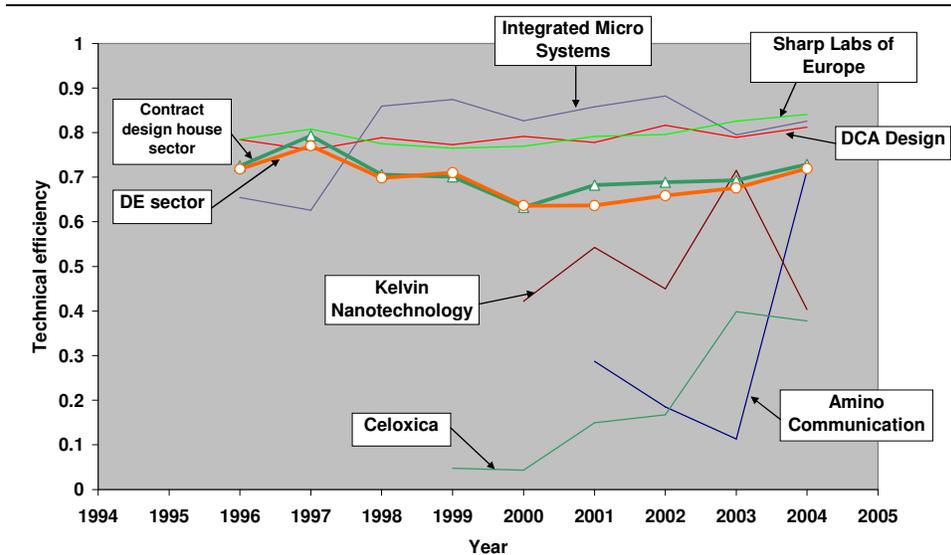
Source: PACEC analysis, ORBIS

Figure 5.21 Evolution of technical efficiency of the UK contract design house sector over the period 1996-2004. Selected companies in the Cambridge cluster (and Roke Manor Research)



Source: PACEC analysis, ORBIS

Figure 5.22 Evolution of technical efficiency of the UK contract design house sector over the period 1996-2004. Selected companies in the Cambridge cluster



Source: PACEC analysis, ORBIS

5.4.19 Technical efficiency in the Cambridge cluster is consistently above the average for both the contract design house sub-sector and for the IDE sector as a whole. Apart from certain companies in certain years, companies in this cluster appear to operate with similar technical efficiency. This suggests that there may be efficiency gains from being clustered in the same region.

What determines technical inefficiency?

5.4.20 The measurement of technical inefficiency using stochastic frontier analysis first requires an estimation of the production frontier. The systematic deviations of companies from this frontier are calculated (giving the measure of technical inefficiency) and are then regressed on a number of variables that are thought to have an impact on technical inefficiency. The results for the UK and cross-country sample are provided in Table 5.8⁵⁵. The top part of panels (a) and (b) in this table gives the results of the production function estimation. The bottom part of the panels gives the results from the subsequent regression of the technical inefficiency estimate on its potential determinants.

Table 5.8 Technical efficiency analysis results using stochastic frontier analysis

Panel (a): UK analysis			Panel (b): Cross-country		
Production frontier			Production frontier		
Variable	Coefficient	t-ratio	Variable	Coefficient	t-ratio
Constant	3.56	29.16***	Constant	3.05	40.89 ***
Current assets	0.48	16.12***	Current Assets	0.52	25.20 ***
Employment	0.40	8.95***	Employment	0.45	15.30 ***
Determinants of Inefficiency			Determinants of Inefficiency		
Variable	Coefficient	t-ratio	Variable	Coefficient	t-ratio
Constant	-1.92	1.79 *	Constant	0.17	0.16
Employment	-1.05	4.80 ***	Employment	-1.30	4.80 ***
Contract Design Dummy	-1.54	2.41 **	Contract Design Dummy	-10.00	5.07 ***
Fabless Dummy	0.33	0.62	Fabless Dummy	-14.48	2.93 ***
Others Dummy	-2.39	2.58 ***	Others Dummy	-6.42	4.32 ***
Age dummy <10	4.90	5.57 ***	Age dummy <10	3.65	4.26 ***
Age dummy 11<25	0.29	0.36	Age dummy 11<25	-0.26	3.64 ***
Non-UK offices dummy	4.04	6.01 ***	UK dummy	-0.35	0.82
University Impact	-0.003	3.56 ***	US dummy	-4.37	3.10 ***
Patents	-0.077	2.23 **			
Total employment	0.00004	2.37 **			

Note: ***: 1% significance; **: 5% significance; *: 10% significance

Source: PACEC analysis, ORBIS

Production frontier

5.4.21 Functional form: A number of different functional forms were estimated in order to gauge which one best fits the design engineering sector. These included the standard Cobb-Douglas functional form, translog functional forms and a flexible Fourier form. The results suggest that the Cobb-Douglas functional form provided the best fit.

5.4.22 Cobb-Douglas production functions are typically of the following form:

⁵⁵ Many specifications were estimated. However, the results presented here represent the most relevant.

$$Y = AK^\alpha L^\beta$$

where Y is a measure of output, K is a measure of capital input and L is a measure of labour input. α and β provide the shares of capital input and labour input respectively in the output produced. Cobb-Douglas production functions assume constant returns to scale (i.e. $\alpha + \beta = 1$). A provides an indication of the scale of production – the amount of output that would be obtained by combining one unit of each input. This gives an idea of the level of technology in the sector.

- 5.4.23 Constant: The constant in the regression takes a value of 3.56 (for the UK analysis). Because the regression is in logarithmic form, one must take the anti-log to obtain the scale of production effect. The effect on the combination of capital and labour is therefore 35.2⁵⁶. In the cross-country regressions, the scale of production effect is lower, at 21.1, suggesting that the overall level of technology is higher in the UK compared with the entire cross-country sample.
- 5.4.24 Capital and labour shares: For the UK the elasticity of output with respect to capital is approximately 0.48, while that attributable to labour is approximately 0.4. In the cross country regression the elasticity of output with respect to capital is approximately 0.52 while that attributable to labour is approximately 0.45.
- 5.4.25 Constant returns to scale: The production functions in both the UK and international samples appears to exhibit constant returns to scale, with the coefficient on capital (proxied by current assets) and the coefficient on labour (proxied by employment) summing to approximately unity. This implies that the marginal cost of operating is constant. This result is unsurprising for contract design houses, as they tend to have low fixed costs and can likely double their output by doubling their inputs. However, for the commodity-based fabless and chipless sub-sectors, the result is a little more complicated. Due to potentially large fixed costs of development of semiconductor chips, increasing returns to scale will be experienced during the initial volumes produced. Once production achieves a certain volume, the marginal cost of producing additional units will likely be low and constant, suggesting constant returns to scale. To further explain this result for fabless and chipless companies it would be necessary to examine how fixed costs are treated in the accounts of these companies (they may tend to have already been written off, i.e. measured), and the scale of production (average costs tend to be constant above minimum efficient scale).

Determinants of technical inefficiency

- 5.4.26 The results of the regression of the technical inefficiency estimates on potential determinants are given in the bottom part of Table 5.8. A negative coefficient implies an improvement of technical efficiency (or decreasing inefficiency) of the firm, as it moves the firm closer to the production frontier. A positive value indicates worsening efficiency (or increasing inefficiency).

⁵⁶ $e^{3.56} = 35.2$

- 5.4.27 The estimates for the determinants of inefficiency have a specific meaning in our model (see Appendix B for technical details). They measure the marginal impact of a change in a variable on the mean of a firm's inefficiency (i.e. its distance from the frontier). In the case of technical efficiency, the impact is measured in terms of variations of turnover for a given level of inputs.
- 5.4.28 Size matters: The results show that size (proxied by employment) matters for technical efficiency. Combining this result with the finding of constant returns to scale in production leads to an interesting conclusion: while firms appear to operate under constant returns to scale, being larger means that the company is likely to be closer to the frontier. A potential explanation could be that larger companies are able to specialise and diversify their capabilities, which could lead to technical efficiency gains. Larger companies will also benefit from the diffusion of capabilities between projects which could also lead to efficiency gains. In addition, larger companies may also benefit from managerial efficiencies, although the benefits from this are likely taper off beyond a certain size.
- 5.4.29 Age matters: Both the UK and cross-country samples show that young companies are likely to be less efficient than older ones. As mentioned earlier, age is a proxy for a number of different effects, including learning-by-doing and accumulated knowledge/capability suggesting these factors are important to the efficiency of firms.
- 5.4.30 Proximity to universities is important: The results show that the coefficient on the university impact variable, which accounts for not only the proximity of the firm to a university but also differential effects of the quality of the university, is negative and statistically significant. It is therefore likely that proximity to good quality universities is good for efficiency. A company which is close to a good university benefits from the rapid diffusion of knowledge (either formally or informally) from academia to industry, and the supply of highly skilled labour. Being located within such a labour market is more likely to reduce the search costs of recruiting appropriate labour. Another benefit of being close to good quality universities revealed during the case study interviews is that of reputation. For example, companies in the Cambridge cluster benefit from the rapid diffusion of research, proximity to a highly skilled labour source, and from being associated with the University of Cambridge's global reputation as a world-leading university in technological research.
- 5.4.31 Innovative areas benefit efficiency: Being close to areas of high innovative activity (proxied by the number of patents issued in the area) is good for efficiency, suggesting that there are positive spillover effects of being close to other innovative companies.
- 5.4.32 Non-UK offices hinder efficiency: Having overseas offices can have a number of benefits, including being able to access crucial overseas markets (such as the rapidly growing Chinese electronics market). Local cultural immersion may also contribute to the design of more customised, competitive products specific for the local region. However, there are a number of costs associated with operating offices overseas. These include the loss of the benefits of tacit knowledge transfer embodied in face-to-

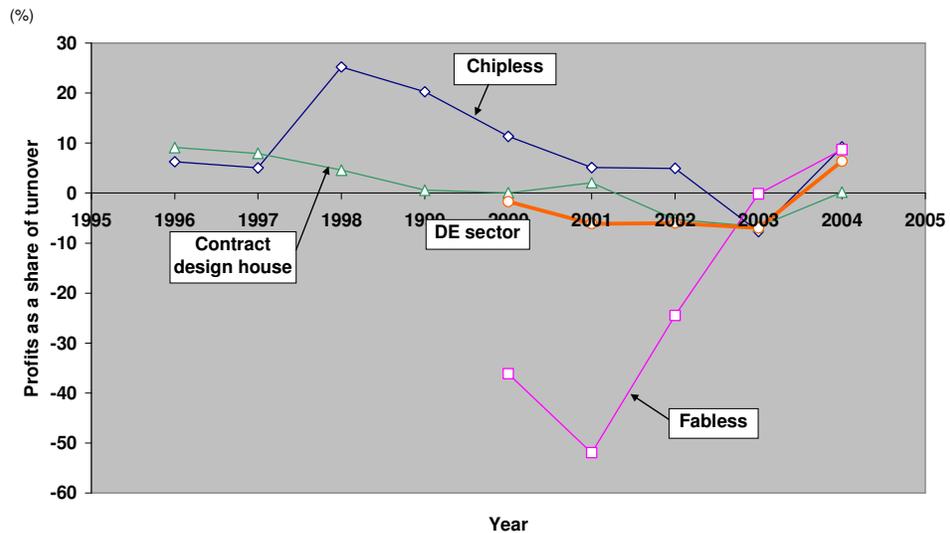
face meetings (although this cost may be declining due to significant advances in information communication technology). *A priori*, it is not possible to predict whether the benefits of operating a 'divided' office outweigh the costs. The results suggest that this is not the case for the design engineering sector in the UK, for whom operating an overseas office hinders efficiency.

- 5.4.33 US companies are more efficient: The cross-country regressions show that US companies are on average, more efficient than non-US companies, with the US dummy being statistically significant at the 1% level of significance (although this result will be biased by the fact that the US sample is limited to publicly-quoted – and hence larger sized - companies).

5.5 The profitability of the design engineering sector

5.5.1 A company's profitability⁵⁷ provides, amongst other things, an indication on whether it can reinvest in further innovative activities, or engage in price competition. A company with sustained negative profits will be unsustainable without external financing.

Figure 5.23 Profitability (profits as a share of turnover, %) of companies in the UK IDE sector and in each sub-sector over the period 1996-2004



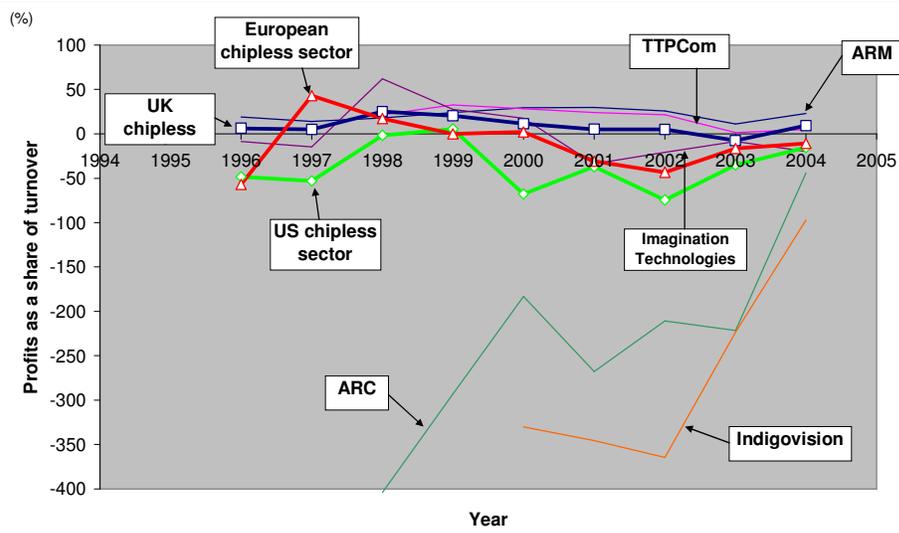
Source: PACEC analysis, ORBIS

5.5.2 Figure 5.23 shows that the profitability of the chipless and contract design house sub-sectors declined over the period 1998-2002 although it showed signs of recovery between 2003 and 2004. This is consistent with the slowdown in the wider electronics industry and the consequent tightening of customers' outsourcing and development budgets.

5.5.3 UK chipless companies fared better than both their European and US counterparts during this downturn (see Figure 5.24), although even the market leaders ARM experienced a drop in revenue, and hence profits, which they attributed to the tightening of budgets within their customer base (ARM, 2003). The market leaders such as ARM, TTPCom and Imagination Technologies retained their highly skilled workforce rather than downsize to cut costs during the downturn. However ARC undertook extensive restructuring during 2003 to reduce costs, including reducing headcount and closing or reducing some overseas offices.

⁵⁷ Note that the profitability of the fabless sector could only be calculated from 2000-2004 due to the dominance of start-ups in the data prior to this period.

Figure 5.24 Chipless sector profitability at the company level over the period 1996-2004 (%)

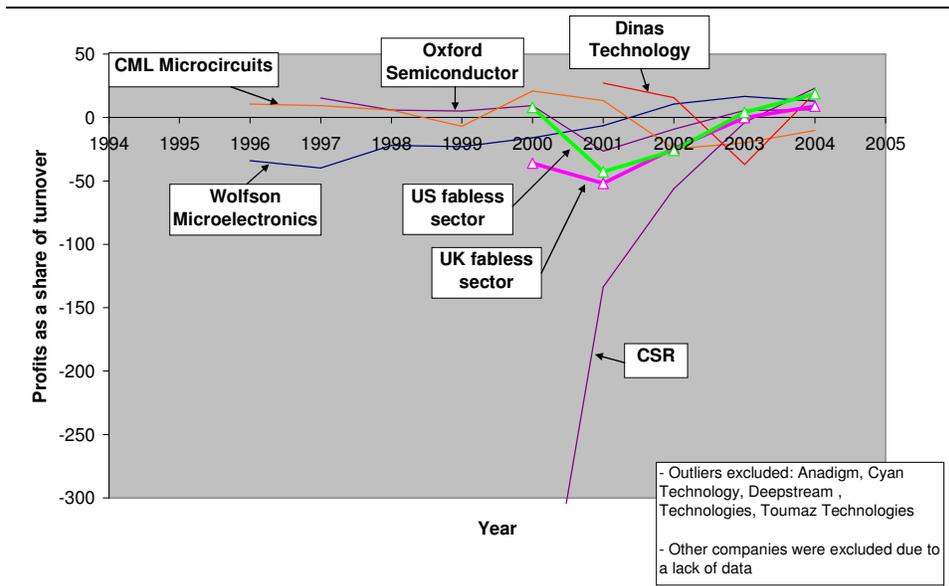


Source: PACEC analysis, ORBIS

5.5.4

The fabless sector was still emerging from its infancy over the early years of the sample⁵⁸, and experienced highly negative, but rapidly increasing profitability. However, it compared favourably with the US fabless sector in terms of profitability. It emerged from negative profitability in 2003, to become the most profitable of the three sub-sectors. This was largely due to improvements in the profitability of CSR and Wolfson Microelectronics (see Figure 5.25). It was also due in part to the improvement in Oxford Semiconductor's profitability in 2003 after a marked decline in 2000.

⁵⁸ The fabless sample could not be extended back to 1996 because most companies in the sector during that time were still in their start-up phase.

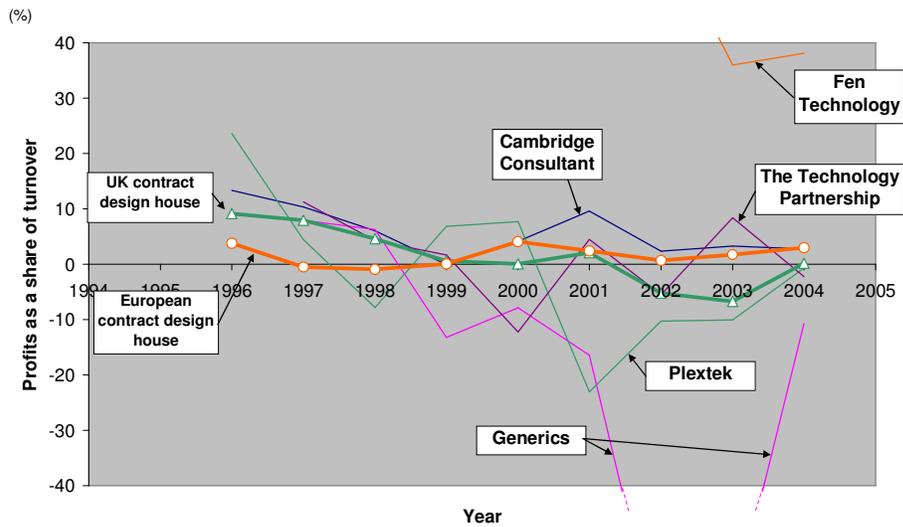
Figure 5.25 Fabless sector profitability at the company level over the period 1996-2004 (%).

Source: PACEC analysis, ORBIS

5.5.5

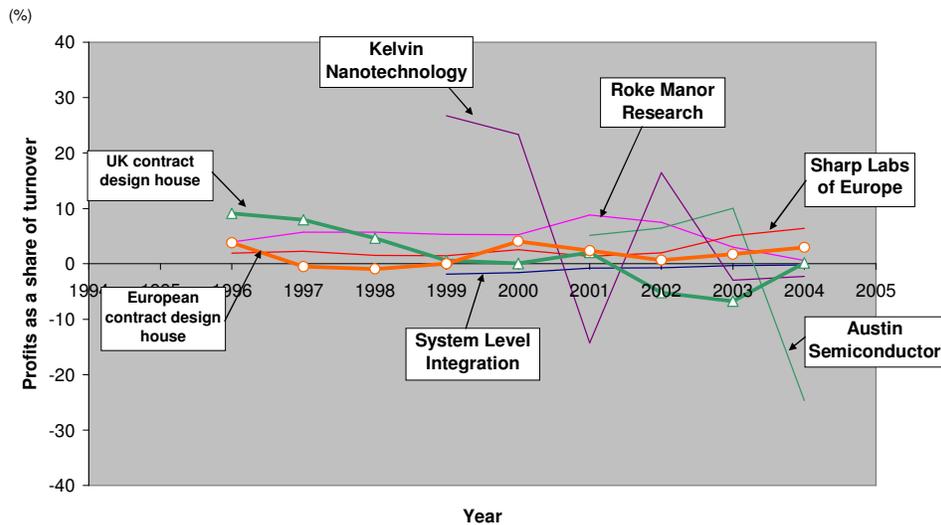
The contract design house sub-sector's profitability was higher than that of its European counterpart over the first half of the sample period until 1999 (see Figure 5.26 and Figure 5.27). UK contract design houses suffered to a greater extent than their European counterparts during the downturn in the electronics industry. The collapse of profitability at Generics in 2001 (see Figure 5.29) was attributed to a fall in demand for technology consulting services (Generics, 2004). Market demand for technology consulting services though picked up again in 2004 and 2005. Generics returned to profitability at the end of 2005, when it forecast solid demand for their technology development and IP exploitation services in 2006 (Generics, 2005). Plextek suffered a similar collapse in profitability, likely resulting from a collapse in its order book as a result of the severe downturn in the electronics industry. Both maintained headcount during these hard times. They realised the importance of retaining the human capital embodied in their workforce, and gambling on a short-lived, temporary downturn, they accepted a period of negative profits. Of the larger Cambridge-based technology consultancies analysed, Cambridge Consultants was the only one to remain profitable throughout the downturn. This may be partly due to the increasing royalties being generated by its equity stake in the increasingly successful spin-out, Cambridge Silicon Radio. Figure 5.27 shows the profitability of a number of other contract design houses. Roke Manor Research, wholly owned by Siemens, weathered the storm in the electronics industry, remaining profitable throughout the downturn.

Figure 5.26 Contract design house sector profitability at the company level over the period 1996-2004 (%). Selected companies



Source: PACEC analysis, ORBIS

Figure 5.27 Contract design house sector profitability at the company level over the period 1996-2004 (%). Selected companies



Source: PACEC analysis, ORBIS

- 5.5.6 The above graphs excluded outliers (unexplained unusual performance) in order to facilitate interpretation of the trends and, therefore, depict the more successful companies.
- 5.5.7 The three sub-sectors appear to be sustainable, with both the chipless and fabless sectors experiencing increased global market penetration, turnover and profitability after the downturn in the electronics industry. The contract design house sub-sector

experienced growth in turnover and improved profitability. A key determinant of the sustainability of design companies is the importance of export markets (primarily the US and Far East), which will be discussed in Chapter 6.

5.6 The performance of the sector

- 5.6.1 It is difficult to capture the true relative success of a firm or sector with one measure alone. For example, a firm which has increased its market share may not necessarily be successful if this is at the expense of long run profitability. Chapters 4 and 5, therefore, presented a number of other performance measures, including market share, productivity, profitability and efficiency.
- 5.6.2 The fabless and chipless sectors both experienced increased global market shares. However, the fabless sector is the only sector that can unambiguously be called successful, with all performance measures increasing over the period. The measures for the other two sectors tell a mixed story. The chipless sector, while increasing its market share experienced stagnant productivity and profitability over the period 1996-2004 with profitability declining over the period 1998-2003, after a large increase between 1996 and 1998. The productivity of the contract design house sub-sector increased over the period while its profitability decreased.
- 5.6.3 The different measures of success are highly (but not perfectly) correlated with each other for the fabless and chipless sectors (Table 5.9). These suggest that large companies exhibit higher productivity, profitability and technical efficiency, while small companies have relatively lower productivity, profitability and technical efficiency.
- 5.6.4 However, the correlations between the different performance measures break down for the contract design house sub-sector (Table 5.10). There is still high correlation between size and productivity, but only a moderate correlation between size, profitability and technical efficiency.
- 5.6.5 Given the high concentration ratios of the three sub-sectors, their performance is driven by the success/failure of a small number of companies. What drives this success is the topic of the next chapter, where the strategies that companies employ to secure competitive advantages are discussed.

Table 5.9 Correlation matrix for the 2004 performance measures for the chipless and fables sub-sectors.

	Size	Technical efficiency ranking	Productivity ranking	Profitability ranking
Size	1.00	0.94	0.96	0.93
Technical efficiency ranking	0.94	1.00	0.89	0.93
Productivity ranking	0.96	0.89	1.00	0.95
Profitability ranking	0.93	0.93	0.95	1.00

Size: Turnover
 Productivity: GVA per employee
 Profitability: profits as a share of turnover
 Source: PACEC analysis, ORBIS

Table 5.10 Correlation matrix for the 2004 performance measures for the contract design house sub-sector.

	Size	Technical efficiency ranking	Productivity ranking	Profitability ranking
Size	1.00	0.12	0.68	0.34
Technical efficiency ranking	0.12	1.00	-0.01	0.05
Productivity ranking	0.68	-0.01	1.00	0.52
Profitability ranking	0.34	0.05	0.52	1.00

Size: Turnover
 Productivity: GVA per employee
 Profitability: profits as a share of turnover
 Source: PACEC analysis, ORBIS

6 Strategies of UK electronics design engineering firms

6.1 Introduction

- 6.1.1 The central aim of this chapter is to establish the sources of competitive advantage and their relative importance. The approach analyses competitive advantage from the perspective of firms entering a new market (either as a new start-up or as an established firm), and from the perspective of established incumbents. The conceptual framework underlying the case studies distinguishes between strategies which are based on price (the transactions cost advantages to the customer from outsourcing and the cost advantages to the firm itself over its competitors) or non-price factors (e.g. innovation in the supplying firm).
- 6.1.2 A key finding of the research programme has been that the broad strategic goals of firms in the sector can be achieved through a range of means. A heterogeneous mix of strategies was observed, with no single profile dominant.⁵⁹ Different companies with different business models, positions in the supply chain and experiences have responded differently to markets, showing varying degrees of technological maturity and complexity, and competition.
- 6.1.3 The chapter has four main sections. The first investigates the broad strategic goals of firms and how they are pursued.
- 6.1.4 The second looks at the mechanisms that firms in the IDE sector have used to compete in markets characterised by very fast moving technology. The ability to overcome the barriers to entering a given market does not depend on a single factor, but rather on the pre-existing contacts and experience of the founders, reputation of the parent company, the capabilities of the proposed products or services, the ability to secure the right partners (with respect to designing the product or service, manufacturing, design tools and customers), finance, and business model.
- 6.1.5 The third section focuses on the mechanisms by which firms face the challenge of developing competitive advantage once they have overcome barriers to entry.
- 6.1.6 This depends heavily on the ability to innovate, not only in technology but also in process and business model. In addition, the ability to collaborate with different partners and access the 'rights design network' is very important. Companies need to be able to conduct deep market research, i.e. understand not only their customers' markets, but also the markets of their customers' customers. Because IDE companies are two or three steps removed from final product markets, and many of the technological product innovations (in the case of the fabless and chipless sectors)

⁵⁹ This conclusion confirms the findings of a five-year research study by the MIT Industrial Performance Center (Berger (2005) *How We Compete*) investigating how company strategies have responded to the challenge of a rapidly changing global economy. The research demonstrates that there is no single prescriptive path down which companies must travel in order to secure competitive advantage. For example, in the wider electronics industry there are highly successful fully vertically integrated firms, such as Intel and Samsung, operating alongside companies that outsource nearly all aspects of design and development, such as Cisco and Dell.

take far longer than the development cycle of their customer's products, the ability to identify future market trends and successful market niches is crucial. It is also important to be able to recruit experienced professionals, be flexible and adaptable in the provision of the solution, and able to offer reduced risk to the outsourcing customer. Lastly, the policy and institutional framework within which these companies operate inevitably influences their ability to develop a competitive advantage in a given market. It is the *interaction* of some or all the above which determine a company's ability to develop a competitive position in a particular market niche.

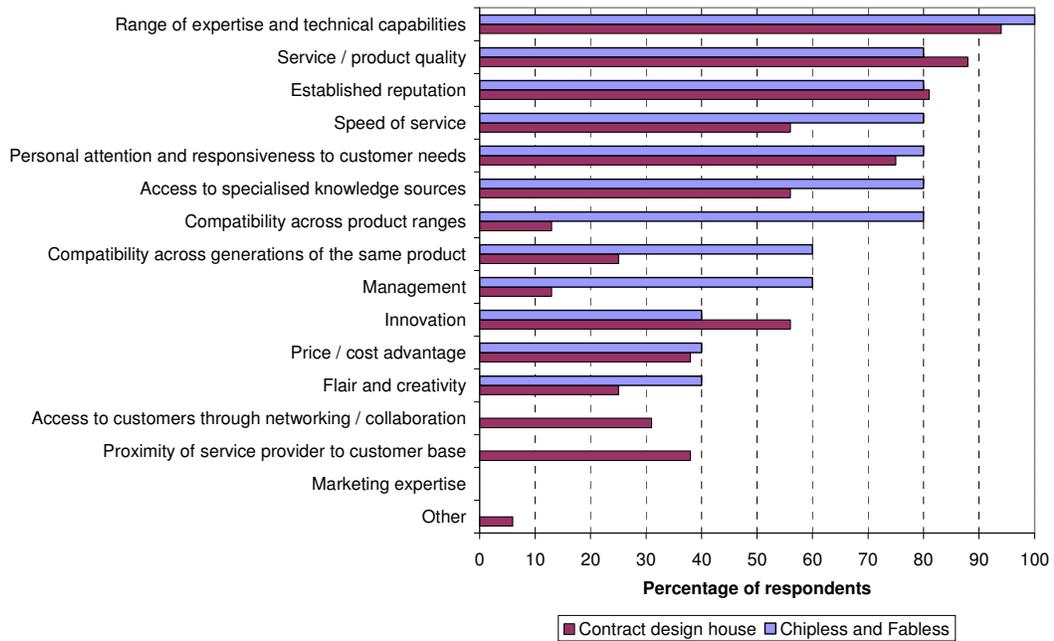
- 6.1.7 Once companies have entered the market and secured a competitive advantage, they can use a number of mechanisms to sustain their position: including developing high switching costs, using standards strategically, continuous innovation, moving to higher tier customers, and broadening the customer and product base. This is the focus of the final section in this chapter.
- 6.1.8 The chapter draws on evidence obtained from (a) in-depth interviews carried out during February 2006 and August 2006 with senior executives in fabless and chipless companies and contract design houses, and (b) a postal survey conducted between August and September 2006, of additional firms. The interviews give a snapshot view of the industry at this time above and beyond what the data can tell us, providing crucial insights into the challenges outlined above.

6.2 Competitive advantage in the design engineering sector

6.2.1 The strategy of securing competitive advantage can be subdivided into price strategies and non-price strategies. Price strategies can be sub-divided further into those which provide cost advantages to the provider of the IDE capabilities (either in the form of products or services), and those which provide reductions in the transactions costs for the customer using the outsourced product or service. Non-price strategy in the IDE sector focuses heavily on innovation, the ability of companies to generate products or services with new or increased capabilities, and improved quality or improved scope, which allow it to differentiate its products or services from its competition.

6.2.2 Evidence on the relative importance of different drivers of competitive advantage was obtained from the interview and survey programmes. The survey asked companies to rate a number of different potential sources of competitive advantage in their main market segment in terms of their importance (Figure 6.1). The most important competitive advantages for all three sub-sectors appear to be ‘non-price’: the ability to enhance the range of expertise, the technical capabilities of the product/service and its quality. Both aspects are linked to the ability to enhance product innovation. Competitive advantages based on price strategies are also important, albeit less so compared with non-price strategies.

Figure 6.1 Competitive advantages of the IDE sector serving the electronics sector.



Percentage of very significant or crucial responses

Source: PACEC Survey

Question: What are your competitive advantages in the main market segments in which you operate? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)

Number of respondents: 21

6.2.3 The important competitive advantages include:

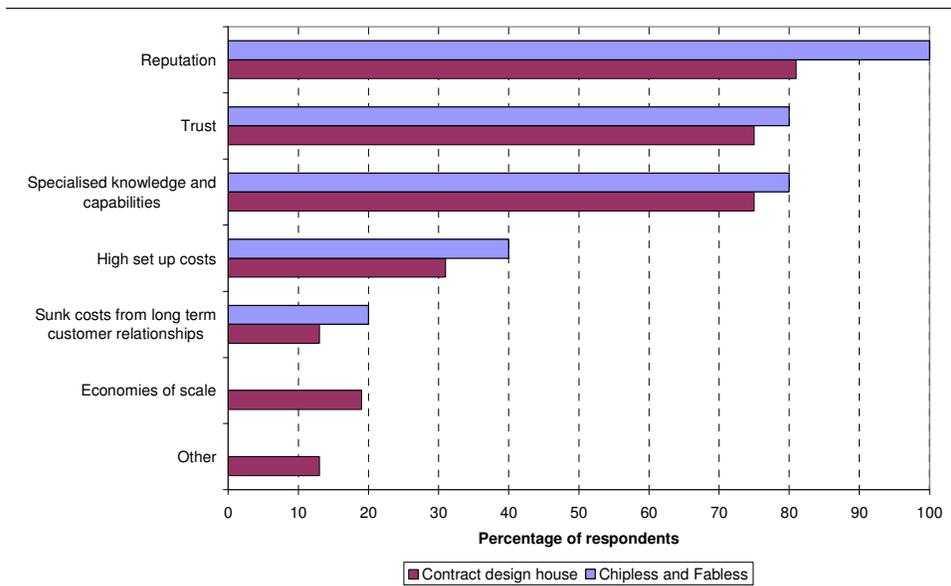
- The range and quality of technical expertise - Product innovation ability is vital. It was rated as the most important competitive advantage, and was described by some companies as the justification for their existence.
- The speed of service – The ability to reduce the time to market is, unsurprisingly, an important competitive advantage in markets with very fast moving products and technologies. Companies can realise substantial gains by being early into market niches, and first to get a particular technology into customer's new products. This will be discussed in detail later in the chapter.
- The reputation of the company. An improvement in the reputation of the company reduces the risk involved in outsourcing.
- The compatibility across product ranges and successive generations (fables and chipless sub-sectors only). This reduces the cost of switching (retraining and retooling) to new products or generations of an existing product, and increases the costs of switching to competitors products.
- The ability to respond to customers' needs. Flexibility and adaptability let companies target future development activities and can lead to a degree of lock-in.
- Cost advantage is seen as a crucial for about 40% of survey respondents. The likely explanation for this lower percentage is market maturity. The competitive advantage of a company offering a new technology in a market with few competitors is not likely to be as cost-driven as in a market niche with an established technology.

6.3 The challenge of entering the market

6.3.1 The market entry decision is a crucial strategic choice in the IDE sector. It is, therefore, important to understand the main barriers to entry in the provision of design to the wider electronics industry (taking the technological capability to develop products as given). The ability of the potential entrant to develop a product or service, based on some minimum level of technological capability, is taken as given. Without this ability a company would not contemplate entering this highly technologically complex sector. That said, the ability to create a product or service over and above this minimum level of technological capability is a crucial source of competitive advantage, as we shall see later.

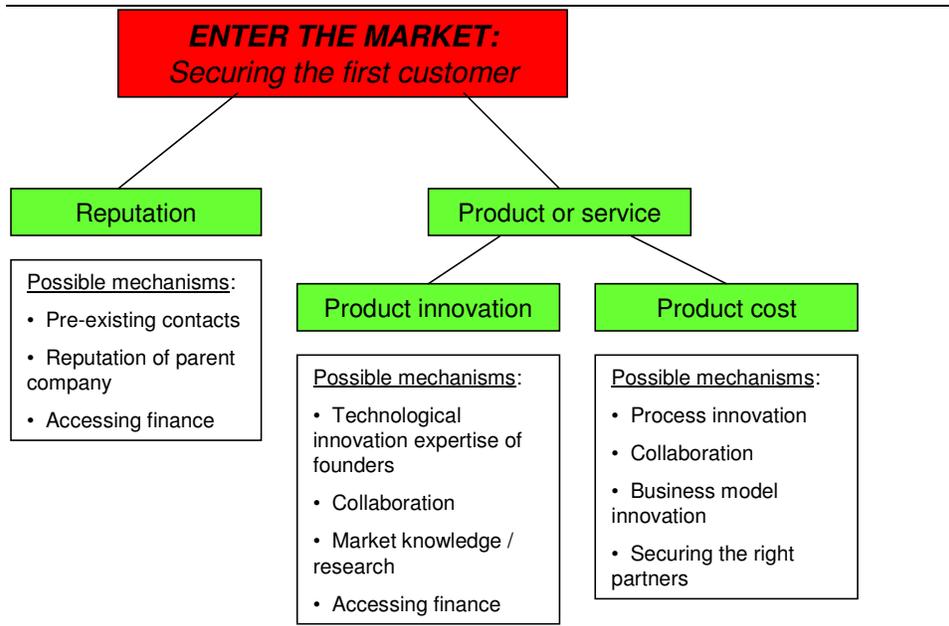
6.3.2 The most important barriers to entry facing IDE firms in the electronics sector include: overcoming the incumbent's reputation, developing trust between the firm and customer, and developing the necessary specialised knowledge and capabilities (Figure 6.2).

Figure 6.2 Barriers to entry facing potential entrants to a company's main market segment.



Percentage of firms in the survey responding very significant or crucial
 Source: PACEC survey of firms
 Question: What are the main barriers to entry currently facing potential entrants to your main market segment? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)
 Number of respondents: 21

Figure 6.3 Entering the market: overcoming the barriers to entry



Source: PACEC research, PACEC survey

6.3.3 Reputation and specialised capabilities were found to be the biggest barriers to entering the market. The question which arises then is, how do companies overcome these to enter their chosen market niche? Figure 6.3 outlines some of the key mechanisms which companies in the electronics IDE sector have utilised⁶⁰. They are divided into those based on reputation and those based on the product or service being provided. The latter is further sub-divided into quality levers (those to do with product innovation) and cost levers. The overall optimal strategy will, of course, depend on the market niche being targeted, and will consist of a number of the mechanisms outlined in the above figure. Some of these key mechanisms will now be discussed.

The critical first customer: overcoming the incumbent's reputation

6.3.4 Since the switching costs associated with adopting a new design are very large, reputation is a crucial competitive advantage for the incumbent. In the semiconductor intellectual property market, it is claimed that “*nobody will be sacked for choosing ARM*”, such is the company’s reputation in the industry. Any company wanting to enter this market must develop a strategy for convincing a customer to switch IP provider.

6.3.5 A number of different strategies were articulated during the interviews, for overcoming the barriers to entry and securing the first customer.

⁶⁰ PACEC interviews

Combining contacts with expertise

- 6.3.6 Given the power of reputation, new entrants to IDE sectors must use mechanisms that may be considered as a substitute for the benefits attached to reputation in order to 'get their foot in the door'. The fundamental requirements of pre-existing contacts, technical expertise and business/commercial awareness are common in all three sub-sectors, although their importance relative to other barriers varies by sub-sector.
- 6.3.7 The interviews revealed that, in the contract design house sub-sector, barriers to entry were fairly low, with reputation seen as the main barrier. However, trust built up through personal relationships in previous roles can allow new entrants to secure the crucial first customer. Companies argued that a greater challenge was to grow beyond the typical small enterprise size of around 30, in order to offer complete project solutions.⁶¹
- 6.3.8 The need for pre-existing contacts and industrial expertise varies across the sub-sectors. The establishment of partnerships is particularly important in the chipless and fabless sectors (e.g. with design tool vendors in the semiconductor intellectual property market, or manufacturing partners in the fabless sector), and an extensive contacts list is required. An emerging successful fabless company in the UK noted that the ability of the company to enter the technologically complex market successfully was due to the managing director's contacts in brand name consumer electronics companies and among high volume manufacturers in China. This enabled the company to quickly form the crucial partnerships between customer, technology provider and manufacturer.
- 6.3.9 A leading UK fabless company noted that its founders had learned valuable lessons within their parent organisation about the requirements and expertise needed by new start-ups. They realised that manufacturing knowledge was crucial even in design-only start-ups, because it reduced redesigning, time-to-market, and development costs. This led them to recruit a manufacturing expert with significant field experience, who could negotiate the complexities of chip manufacturing.
- 6.3.10 Companies that are formed from the spin-out of research and development divisions from large electronics OEMs may also take their customers with them. ARM (as described in Chapter 3) was formed by spinning out an inhouse R&D division to exploit new technology for an existing customer (Apple).

Price competition

- 6.3.11 Price competition is likely to be important if the new entrant's product is not superior to incumbents'. This lower price is unlikely to be optimal for the new entrant, unless they can produce at lower cost, and will need to be maintained until reputation has been established before prices can be increased. This requires significant financial backing from the 'start-up' through to the entry phase to cover the sunk costs of product development and the establishment of a reputation.

⁶¹ See the discussion on developing and sustaining competitive advantage.

6.3.12 The process described above was how a start-up company entered the semiconductor intellectual property market with a strong incumbent whose reputation and very strong customer relationships precluded entry on capability alone. Entry was enabled by focusing on customers who could not afford the incumbent's more expensive products. As the entrant developed its reputation it was able to target increasingly prestigious customers for whom track-record and reputation were paramount. Once it became established, it was able to raise prices to increase its revenues. Accomplishing this however, required significant financial backing during the 'start-up' phase, as it is would have not been possible otherwise to cover the sunk costs of both the development of the products and the establishment of a reputation.

Product competition and market identification

6.3.13 A typical non-price strategy is to develop a superior product. The development of products 'ten times' better than currently available has been effective in a number of cases. Superior product performance includes the potential to reduce customer costs, as well as superior functionality. Companies that have successfully used this method have also tended to secure their first customer through work for their parent company. Spin-outs from technology consultants such as Cambridge Consultants and The Technology Partnership, have been very successful at entering the market in this way.

6.3.14 Cambridge Silicon Radio made significant advances in the highly successful Bluetooth wireless communication technology, a radio technology that enables low power consumption wireless communication between devices. The technology, capabilities and ideas of the founders were nurtured by their experience at Cambridge Consultants. The creation of what was thought to be the first integrated single chip Bluetooth system allowed customers to add Bluetooth capability at much lower cost. The advanced capability of CSR's Bluetooth technology products was superior to other products that existed at the time and allowed the company to enter the market based on product capabilities rather than simply price.

6.3.15 TTPCom was formed out of a communications development team at The Technology Partnership, another successful technology consultancy in Cambridge. The company's business model was based on the belief that the GSM mobile phone standard could vastly increase the capabilities of its customers' products. Its first customer was an existing customer of The Technology Partnership. The ideas underlying TTPCom's initial product offering were nurtured and developed within the Technology Partnership.

6.3.16 ARM provides another example of the need 'to develop something ten times better than currently available'. When ARM started in the late 1980s, Intel and Motorola dominated the market for microprocessors, but were more interested in striving for continually increasing performance. The founders of ARM realised that there was a significant market in mid-performance programmable cores that did not require the vastly superior performance of the Intel or Motorola processor. They realised that there were significant advances to be made in the way different functions could be

integrated, thus allowing increased capability and functionality. All of this could be achieved using the prevailing technology and, therefore, required little additional research. By selecting this market, ARM was targeting those products that were very cost sensitive, and required increased functionality rather than vastly increased performance.

- 6.3.17 ARC saw the ability to configure processor cores as having vast potential, and indeed, there are now signs that the configurable processor market will rapidly increase in importance, relative to the non-configurable processor market, over the next 5 years. It is forecast to increase from 8% of all cores produced in 2006 to approximately 25% in 2010.⁶²

Association with parents with established reputations

- 6.3.18 Spinning out from a highly successful contract design house or OEM provides entrants with some reputation assets. Joint ventures or other forms of collaboration with the former parent can augment entrant reputation, as well as providing a route to market.

Finance

- 6.3.19 The relative importance of raising finance varies by sub-sector and market niche. Barriers to entry and set up costs are low in the contract design house sub-sector, and so the financial requirements for entry are lower. The cost of computers and software is several orders of magnitude lower than the fixed costs associated with the chipless and fabless sub-sectors. This is primarily because the business of contract design houses is typically to sell the expertise of their consultants, with the purchase of project-specific tools and equipment typically built into the project price.
- 6.3.20 In the chipless and fabless sectors, the fairly large fixed costs of developing the initial product act as a significant barrier to entry. These costs are largely due to the time it takes to develop the technological capability required to design highly complex systems. Any firm attempting to enter an area with similar technologies to established firms will face very large fixed costs simply to develop a technological capability that can compete with the incumbent. Costs could be minimised through various means, such as acquisition of other companies or design teams, but all require substantial up-front investment.
- 6.3.21 The ability to secure finance in the chipless and fabless sub-sectors, therefore, becomes a crucial initial competitive advantage. The most common source of financing is venture capital. Cambridge Silicon Radio has been very successful in this, securing funding from 3i, Intel Capital and ARM Holdings (among others) during different investment rounds. 3i has described their reasons for being eager to invest in CSR:

⁶² EETimes 31.10.2006, "Configurable processors on the rise, speakers say".

“As soon as you met the management team at CSR, you knew they had exactly the right ingredients: scientific genius, allied to powerful ambition. This was clearly a team that was hungry for success on a big scale. Our role was to do everything we could to help them grow - introducing contacts, sourcing talent, helping with contract negotiation.”⁶³

- 6.3.22 Intel, one of the largest global semiconductor companies, has an active policy of investing in companies pursuing innovative technologies, recognising that it needs to access innovation outside the company. Its corporate venture investments total more than \$4 billion since 1991, involving approximately 1,000 companies in more than 30 countries. Through its venture capital arm Intel Capital, it has gained access to technologies whose benefits have not yet been fully developed or demonstrated. By investing in CSR, Intel gets access to the latest developments in Bluetooth technology and advanced knowledge about other potential technologies. CSR in turn gains financing to develop their products, the seal of approval of one of the market leaders in semiconductor technology, and advance knowledge of future trends in its customer base. Understanding how the market for its products will change over the next 3-5 years is a crucial competitive advantage, given the long product development times for its system-on-chip solutions and the very short final user product development times of its customers.
- 6.3.23 The investment strategy of ARM Holdings demonstrates an additional motive. CSR used ARM cores to power its Bluetooth devices⁶⁴. By investing in CSR's success, ARM helps to guarantee a market for its own semiconductor intellectual property products and gains knowledge of where CSR's market is heading. In turn, CSR gains access to knowledge of future ARM products and developments and can ensure that there will be appropriate processors for future CSR products.
- 6.3.24 Venture capitalists can also usefully act as a filter to select only those companies with realistically ambitious business plans, led by people who are not only technologically aware, but also commercially aware.
- 6.3.25 In addition to venture capital and financial backing by the parent company, groups of 'angels', hedge funds, government Enterprise Capital Funds (ECF) and the Alternative Investments Market (AIM) of the London Stock Exchange, are all additional important sources of financing for start-ups.⁶⁵

⁶³ 3i investor (<http://www.3i.com/approach/venture-experience.html>)

⁶⁴ <http://www.arm.com/news/4801.html>

⁶⁵ Library House (2006) "The Supercluster Question: the Cambridge Cluster Report 2006"

Developing the first product

- 6.3.26 The companies interviewed described a number of different mechanisms through which available technologies were used to complement existing capabilities.
- a License technology
 - Forming close ties with a semiconductor intellectual property provider enabled a young fabless company to license its integrated circuits and focus on offering an innovative package of functionalities with the semiconductor intellectual property. Once they had developed the required chip design skills, they moved from 'IP packaging' to 'IP creation'.
 - b Collaborate with universities
 - Companies that were spun-out from universities or whose founders are closely linked to universities are better-positioned to collaborate with universities.
 - c Build on existing capabilities gained from the parent organisation
 - A large number of start-up companies in the IDE sector emerged from the downsizing of research divisions in their parent companies. In many cases, those who left remained together, either by forming their own startup, or collectively joining an existing design company. In a number of such cases, the reputation barrier was significantly lowered and facilitated entry to the market. However, growing and sustaining a competitive advantage turned out to be a challenge.
 - A number of companies interviewed were formed from the separation of research divisions from their parent companies. TTPCom was formed when the Computers and Communications research division became independent of the TTP Group. Expertise gained through collaborative development funding with customers of the research division⁶⁶ enabled the group to develop a competitive product.

Selecting an appropriate business model

*"Technology without a business model to take it to the customer base has no value whatsoever"*⁶⁷

- 6.3.27 The choice of business model for companies which decide to outsource manufacturing (contract design house, chipless and fabless) has implications for their barriers to entry, risk and cost profiles, and transactions costs. The risk associated with licensing semiconductor intellectual property is extremely high, but reputation barriers are much lower than for contract design houses. A start-up following the fabless business model will require much more initial financing than for the chipless or contract design house business models. ARM (the research division of Acorn) faced prohibitive barriers to selling physical microprocessors in its market segment at that time. Its innovative semiconductor intellectual property licensing and royalty model provided a unique mechanism for overcoming the barrier to entry, by reducing the risk associated with using their cores.

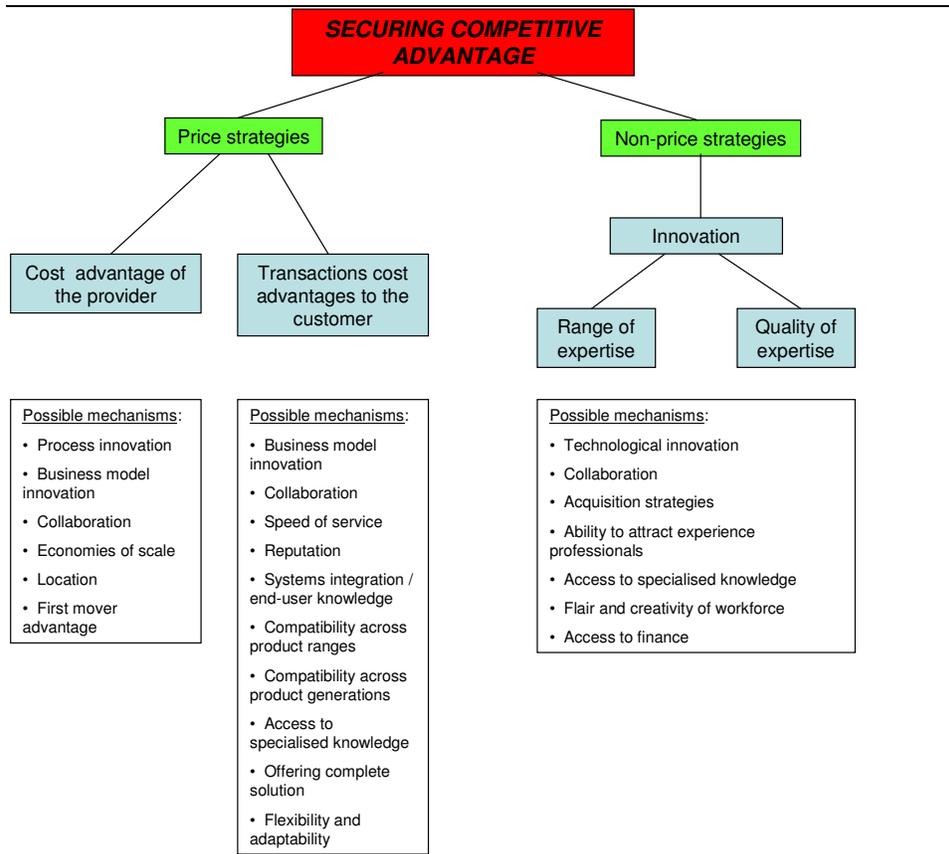
⁶⁶ TTPCom website: <http://www.ttpcom.com/en/about/history.htm>

⁶⁷ Interview with a leading semiconductor intellectual property provider.

6.4 The challenge of securing and sustaining competitive advantage

6.4.1 Once a company has overcome the barriers to entry, it has to develop and sustain a competitive advantage. Innovation and collaboration are central to this, but cannot be taken in isolation from other capabilities, such as accessing the right partners, systems integration knowledge, awareness of the end-user market, brand development, and location. It is the interaction of these different factors that creates competitive advantage of a company. In this respect there are significant differences between the fables and chipless, and contract design services sub-sectors. Figure 6.4 sets out some of the mechanisms for securing competitive advantage.

Figure 6.4 Mechanisms for securing competitive advantages

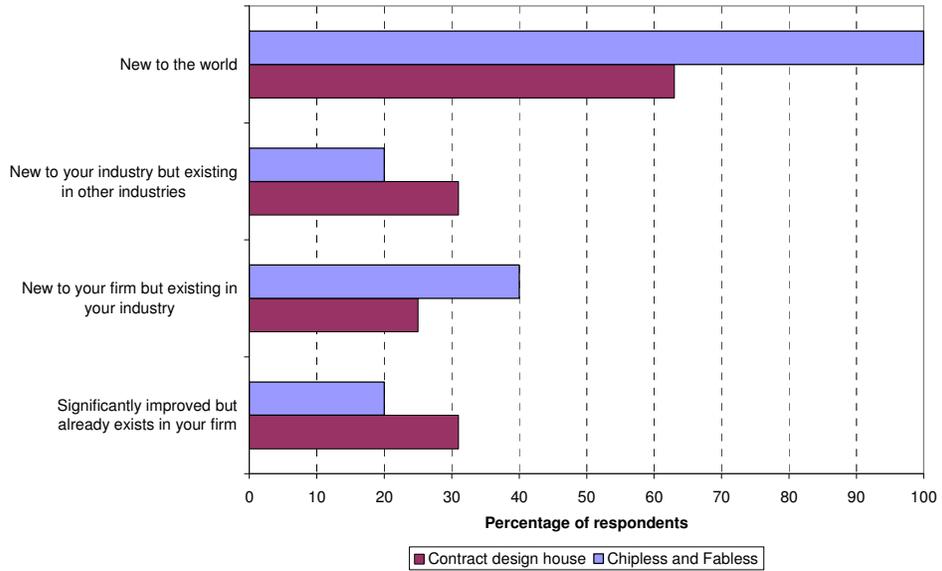


Source: PACEC research, PACEC survey

Innovation: drivers and impacts

6.4.2 In the survey, companies were asked how important innovation was to their competitive advantage. Innovation in capabilities or products was seen as important for all respondents in the fabless and chipless sectors and for 63% of respondents in the contract design house sector (Figure 6.5).

Figure 6.5 Importance of introducing new innovations in capabilities or products to a company’s competitive advantage

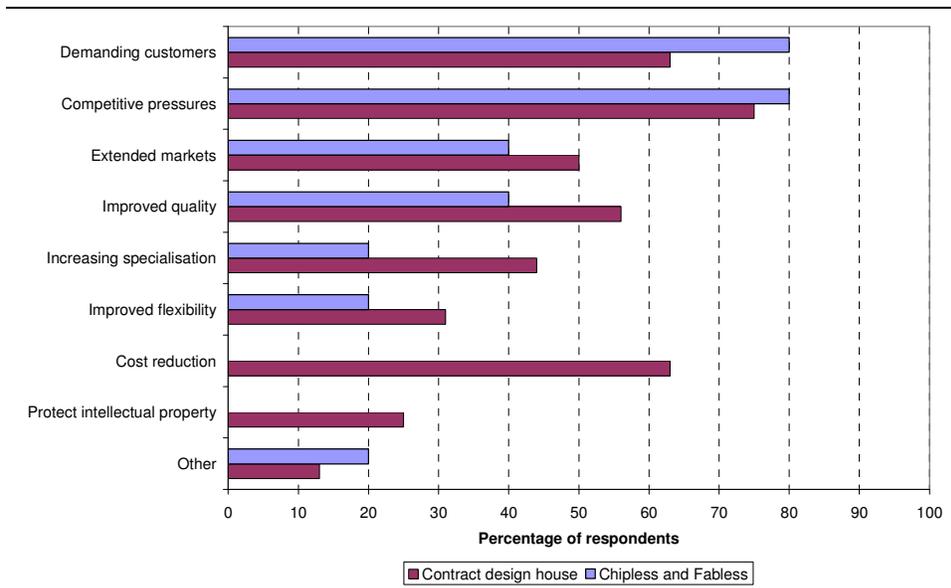


Percentage of very significant or crucial respondents
 Source: PACEC analysis
 Question: Thinking about your business as a whole, have you introduced any of the following types of innovation over the last 5 years (either new or significantly improved)? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)
 Number of respondents: 21

What drives innovation?

6.4.3 Firms cited competitive pressures and demanding customers as the most important drivers of innovation in the IDE sector, although improved quality of products and services, and extending markets were also cited as important (see Figure 6.6). Cost reduction was only identified as an important driver of innovation in the contract design house sector, with 60% of respondents noting its importance.

Figure 6.6 Main drivers of innovation

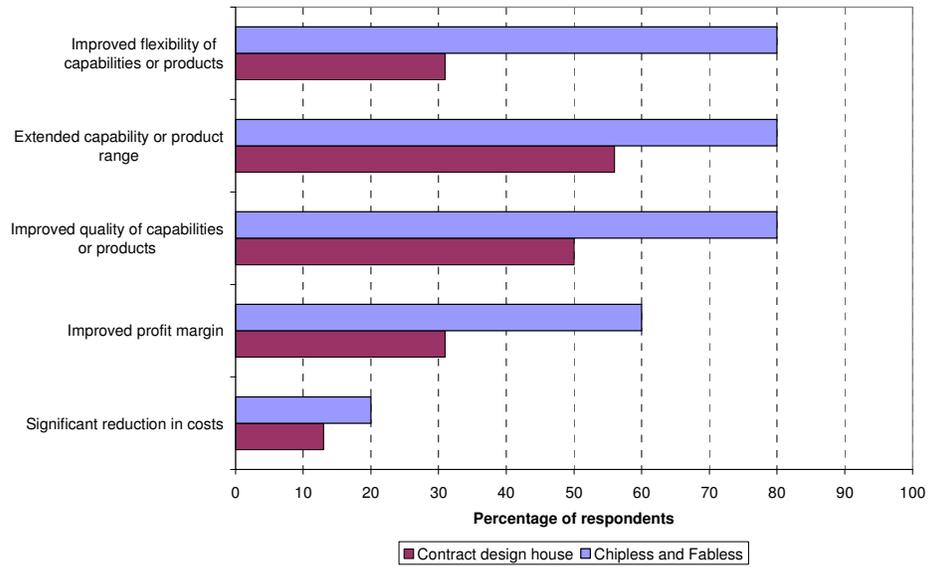


Source: PACEC analysis
Question: What are the main drivers of innovation for your business as a whole? (Please tick as many as apply)
Number of respondents: 21

How does innovation impact a firm's activities?

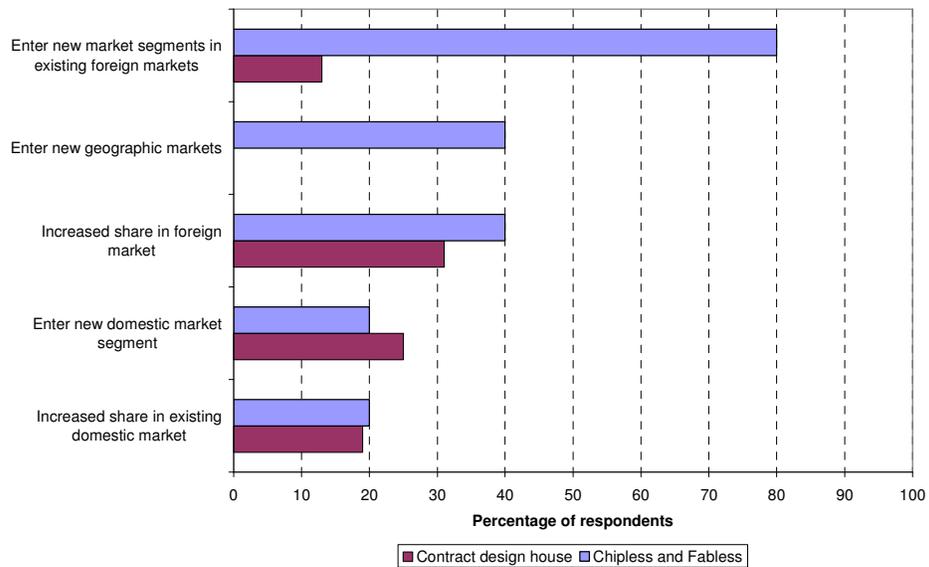
6.4.4 Firms were then asked to rate the various impacts of innovation in terms of importance on their competitive advantage. The impact categories considered were overall effects, effects on market share, effects on the ability of the firm to interact with customers, universities and collaborators, and effects on the firm's ability to respond to regulatory requirements. The results are presented in Figure 6.7 to Figure 6.10.

Figure 6.7 Overall effects of innovation on the firm



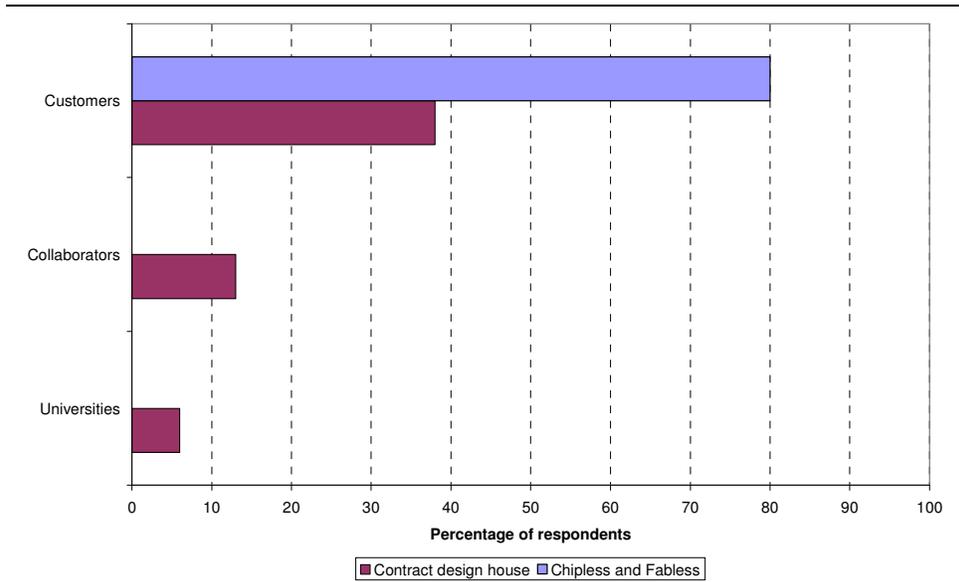
Percentage of respondents ranking the effect as very significant or crucial for their competitive advantage
 Source: PACEC Survey
 Question: Please indicate whether the innovations mentioned [above] have had any overall effects on the firm? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)
 Number of respondents: 21

Figure 6.8 Effect of innovation on the market share of the firm



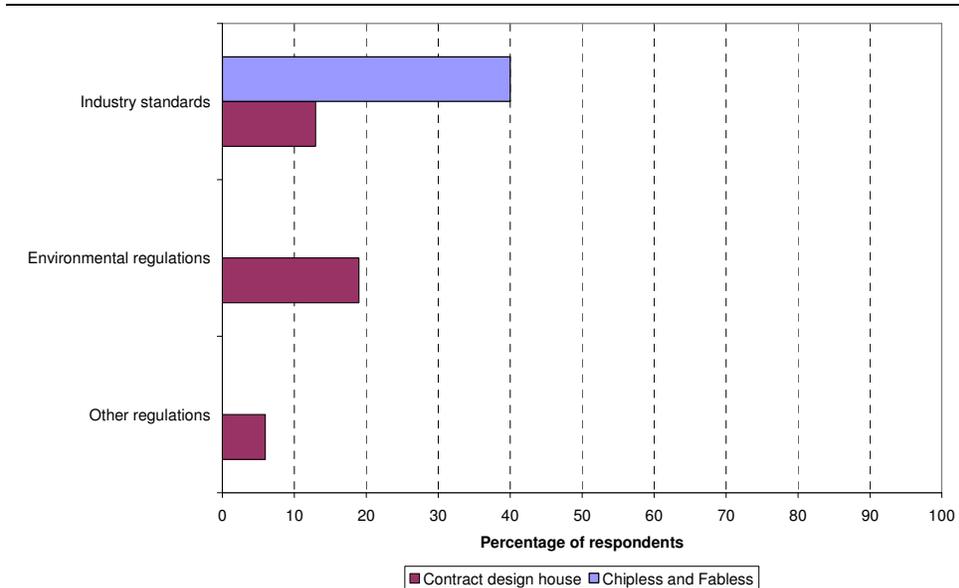
Percentage of respondents ranking the effect as very significant or crucial for their competitive advantage
 Source: PACEC Survey
 Question: Please indicate whether the innovations mentioned [above] have had any effect on the improvement in the market share? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)
 Number of respondents: 21

Figure 6.9 Effect of innovation on the improvement in the interaction of the firm with outside partners



Percentage of respondents ranking the effect as very significant or crucial for their competitive advantage
Source: PACEC Survey
Question: Please indicate whether the innovations mentioned [above] have had any effect on the improvement in the firm's interactions with outside partners? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)
Number of respondents: 21

Figure 6.10 Effect of innovation on the improvement in the firm's response to government regulatory requirements



Percentage of respondents ranking the effect as very significant or crucial for their competitive advantage
Source: PACEC Survey
Question: Please indicate whether the innovations mentioned [above] have had any effect on the following? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)
Number of respondents: 21

6.4.5 Figure 6.7 to Figure 6.10 show that for the fabless and chipless sectors, the greatest impact of innovation on competitive advantage is via:

- Improved profit margin
- improved quality of capabilities or products
- extended range of capabilities or products
- flexibility of capabilities or products
- ability to enter new market segments of *existing* foreign markets
- improved interaction between firms and their customers
- improved ability to respond to industry standards.

For contract design houses, there are fewer perceived impacts of innovation on their *capabilities*. The greatest impact of innovation was on:

- improved quality of capabilities or products
- extended capability or product range
- improved interaction between firms and their customers.

About a third of respondent contract design houses thought that the impact of innovation on their profit margin, the flexibility of their capabilities, and on the ability to increase their share in foreign markets, was very significant or crucial for their competitive advantage.

Technological and process innovation

6.4.6 The discussion now turns to innovation in technology (i.e. innovation in products (for fabless and chipless), capabilities (for contract design houses), process (how companies go about providing their products or capabilities), and business model (how companies go about taking their products or capabilities to market).

Technological innovation

6.4.7 Technological innovation in products is fundamental to the IDE sector serving the electronics industry, particularly for firms in the design commodity sub-sectors (fabless and chipless) which sell either physical products (chips) or intellectual property. In the contract design house sub-sector, innovation is in the capabilities provided to customers.

6.4.8 A leading fabless company noted:

“Engineering technology is the driver for the company ... everything else acts as a support for developing this engineering technology. Other factors are important ... but if you don’t have a good chip, they are pointless.”

6.4.9 None of the fabless and chipless companies interviewed claimed to undertake much research in new technologies. Companies are always looking for innovative ways of exploiting *existing* technologies. A leading chipless provider noted that they operate

behind the technology frontier, using existing, proven technology in innovative ways to create products that “make customers lives easier”.

Panel 6.1 Innovation potential in the mobile phone market

There is a lot of room for innovation to achieve lower costs or improved performance, e.g. in creating single-chip as opposed to traditional double-chip phones, and in the enabling software.

However, there is much less room to move away from the many complex standards and regulations that govern mobile phones, or the compatibility rules of operators (such as Orange, Vodafone) on whose networks the phones must work.

6.4.10 Companies in the fabless and chipless sectors note the importance of continuous innovation to keep existing competition at bay, and the emerging threat from low cost countries which are quickly developing design capabilities. A leading chipless company noted that they are not yet concerned with the emergence of a rapidly improving mobile telephony capability in low cost countries since this is confined to second generation (2G) technology, while they, by contrast, are concentrating on 3G technology. It is unclear whether Indian and Chinese companies can catch up faster than those in ‘advanced countries’ can produce newer generations of technology.

6.4.11 For the contract design house sub-sector, most of the technological innovation that firms undertake is for their customers as part of the contracted services. Contract design houses sell the capabilities of their ‘human capital, and innovation in these capabilities arises primarily through the projects for, and interactions with their customers. They also appear to do little R&D themselves. In some cases, acquisitions or joint ventures are pursued to develop additional capabilities or access capabilities located in different regions.

Process innovation

6.4.12 Process innovations in the IDE sector come about in a number of ways.

6.4.13 In contract design houses, process innovations tend to emerge from projects, where insights are gained into customers’ working practices, and the requirements of customers’ customers. Through deep exposure to their many clients, firms can continually optimise the processes they use to provide their capabilities and maximise the value delivered to their customer.

6.4.14 All three sub-sectors are susceptible to general shocks to the innovation system. New regulations have forced publicly quoted companies to implement new business processes, to the benefit of customers. Two examples are the adoption of ISO 9000, and the adoption of integrated order management systems such as SAP. Companies listed on US stock exchanges have been forced to adopt such processes by the Sarbanes-Oxley regulations brought in to combat corporate fraud. A leading chipless company noted that, while the adoption of these business process systems was troublesome, they often led to process improvements and benefits for their customers.

Developing capabilities

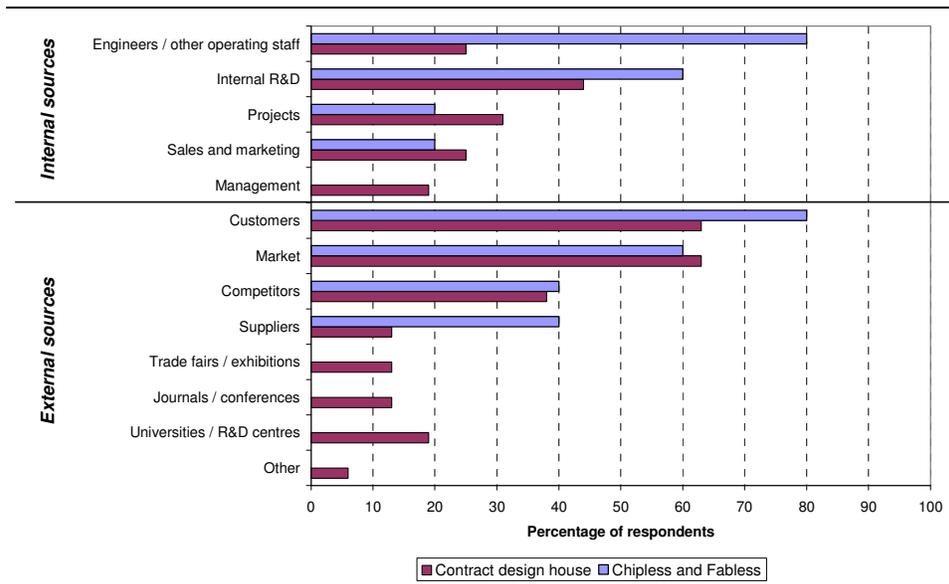
- 6.4.15 Due to the relatively small size of many companies in the sector, new capabilities and technologies are typically acquired (often through hiring) rather than developed in-house. The largest companies in the sector undertake internal research to produce the next generation of products using existing technologies. A leading fabless company noted:

“We don’t aim to push back the technological frontiers. We don’t aim to bring [technologies] out of the laboratory and into products quickly. We aim to use [the technologies] out there in an effective and efficient manner to create new chips”.

- 6.4.16 Most of the companies interviewed had a history of acquiring as a means of developing capabilities quickly. For example, fabless companies involved with wireless communications or entertainment chips and systems, are acquiring automotive electronics companies to support their entry into the automotive electronics market.

- 6.4.17 The survey highlighted some of the important sources of knowledge used in the development of products and capabilities. Figure 6.11 shows that the most important sources of knowledge for innovation in all three sub-sectors are the market and customers, while engineers provide an equally important source for the fabless and chipless sectors. Internal R&D is very important, with 60% of fabless and chipless respondents noting it is very significant or crucial, compared with 44% of contract design houses. About 40% of companies in all three sectors believed that competitors provided a very significant or crucial source of knowledge for innovation.

Figure 6.11 Main sources of knowledge for improving products and capabilities



Percentage of very significant and crucial responses in affecting a firm's competitive advantage
 Source: PACEC Survey
 Question: Thinking about your business as a whole, what are the principal sources of knowledge for improving the range and quality of your firm's capabilities? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)
 Number of respondents: 21

Business model innovation

6.4.18 In a sector where technological innovation is the norm, the ability to innovate in other ways becomes a key differentiator. The companies interviewed described a number of innovations in their business models which enabled them to reduce customer risk and cost, and increase speed to market, flexibility and adaptability.

Offering a complete solution

6.4.19 Companies in all three sub-sectors are moving towards offering complete solutions to customers. There are a number of reasons for this; including capturing a larger amount of the value in the final product, increasing the switching costs for the customer, and reducing the risk that a customer faces when using their services. The most successful UK chipless companies interviewed now offer complementary services such as configuration software, testing and EDA tools with their core product. Each reduces the cost to the customer of buying their semiconductor intellectual property. This increases customer loyalty because investment in training is needed to use these tools, which makes them more likely to consider the same company for upgrades or other products.

6.4.20 Chipless companies are also moving into systems design. ARC now sells not only the IP for microprocessors, but for complete sub-systems and systems in the video and audio markets. One of their products integrates their optimised RISC processor with fully portable media functionality that customers can place on their SoC. By

licensing pre-verified sub-systems, ARC has reduced the costs to the customer of purchasing components from different vendors and subsequently integrating them. By providing programmable sub-systems, it reduces the customer's costs of differentiating products.

- 6.4.21 A senior executive at a leading chipless company summarised the driver behind their desire to offer the complete solution saying:

"What [our company] is doing is helping the [development] part of the product lifecycle by shortening the lifecycle, reducing the risk, reducing the costs and reducing the time to market. Anything that we can do to help our customers reduce the net cost and increase the net gain of the product over its lifecycle is a valuable thing."

- 6.4.22 Some of the most successful UK fabless companies interviewed are now beginning to package the chip together with the embedded software and surrounding functionalities, sometimes encapsulated within a 'System-in-a-Package' black box that the customer can plug into their own system. There is growing evidence that embedded software is where future value will be captured, as this is what truly differentiates the functionalities of the chips being developed.

- 6.4.23 A leading fabless company in the digital audio market segment offers a complete digital audio solution by integrating the RF chip and baseband chip, either on a single chip (System on Chip) or in a single 'black box' (Silicon in a Package). This enables them to reduce the size of the product, thus reducing the footprint on the customer's printed circuit board. The embedded software (which truly differentiates the functionality) is also included. By offering a complete solution that customers can simply plug into their own product, the company has reduced the need for customers to source different components and software from different vendors. This reduces the transactions costs the customer faces when sourcing components from third parties, due to the far lower integration costs. By providing the complete 'plug-and-play' solution, the customer is also assured of compatibility between the different component parts (RF chip and baseband chip), thus reducing the amount of testing and redesign required, which reduces both the cost and the time to market.

- 6.4.24 These developments follow general trends in the wider electronics industry, where companies are offering services with their products in an attempt to move up the value chain, and develop lock-in with their customers, using resources that can generate revenue with low marginal cost. An increasingly common example is fabless companies beginning to license their design libraries.

The 'virtual ODM'

- 6.4.25 The large contract design houses (such as The Technology Partnership, Plextek, Scientific Generics (now Sagentia) will also find, negotiate and manage the manufacturing relationship between customers and low cost third party contract manufacturers, normally until a certain yield of production has been achieved. Many

interviewees noted the challenges in finding reliable low cost manufacturing partners, especially if new to the industry. By effectively leveraging their knowledge and contacts in low cost manufacturers around the globe, contract design houses can greatly reduce the potentially high asymmetric bargaining power between their often small customers and often very large and powerful contract manufacturers. In this way, they can substantially reduce the risk of outsourcing manufacturing.

- 6.4.26 In addition, customers are able to access the design capabilities of the UK *and* the low cost manufacturing regions through a *single* third party (the contract design house), rather than sourcing the design from one company and the manufacturing from another. By providing this complete solution, contract design houses are also able to reduce the development costs associated with managing multiple, potentially complex relationships.
- 6.4.27 In return for accepting part of the risk of managing the manufacturing relationship for their customers, the fee structure for contract design houses is changing fundamentally, being increasingly composed of the traditional upfront lump-sum fees complemented by royalties from production runs.
- 6.4.28 Contract design houses have, therefore, become *de facto* 'virtual ODMs', as by a senior executive in a successful technology consultancy claimed. ODMs design products and manufacture them in in-house facilities under contract from customers. The larger UK contract design houses now design the products and manage third party contract manufacturing in low cost regions.
- 6.4.29 This fundamental shift in the capabilities offered by contract design houses has led to their increasing commitment to the success of customers' product's success, and process innovation to reduce the number of costly redesigns in the post-production development phase.

Offshore and outsource?

- 6.4.30 The IDE sector exists because of the outsourcing activities of their customers. Outsourcing has been enabled by the increasing modularisation and standardisation of the technology (see chapter 2). Modularisation can sometimes apply to the products of the fabless and chipless sector. Like their customers, they are opening up design centres in low cost regions and/or outsourcing to third parties, partly to realise cost savings, and partly to access rapidly growing emerging markets and the growing design skills in offshore regions. Bangalore in India, and Shanghai in China typically undertake the more routine design elements, but in time are likely to move towards higher value added design activities. A number of fabless and chipless companies interviewed noted that in the near future their design operations were likely to be expanded abroad rather than in the UK. However, a contract design house and a fabless company interviewed mentioned the downside of higher monitoring costs.

- 6.4.31 A relatively new, highly successful fabless company noted that they design all core technologies in the UK but outsource non-core routine activity, such as customisation, to locations near the customer base. In this way, they reduce the co-ordination costs between themselves and their customers, while designing and operating at a distance. However, they only outsource specialist capabilities locally to maximise knowledge transfer. Like their customers, they also outsource to manage 'peaks and troughs' in demand, again applying the criterion of what is core.
- 6.4.32 Typically, chipless companies outsource cost-sensitive, routine software development to low cost areas, such as India. Where they lack in-house capabilities, they outsource either locally or to the knowledge centres, such as the US. They see China as an increasingly attractive proposition for future outsourcing for cost reasons, but also with the aim of developing a local presence in the market.

Flexibility and adaptability

- 6.4.33 It is well known that in fast-moving markets such as the electronics industry, flexibility and adaptability provide competitive advantage. In addition, being aware of the trends in the final user market is equally important.
- 6.4.34 Most of the leading chipless companies interviewed are increasingly flexible in the way they supply their markets. For example, ARM provides not only hard cores but soft cores and architectural licenses⁶⁸. There are trade-offs between performance and the flexibility afforded to the customer. For example, the hard core license provides the best performance because ARM have optimised the design for a particular implementation process which is fixed by the license. However, the hard core may be more difficult to incorporate into the rest of the design, thus increasing the overall cost of design. A soft core will be compatible with the rest of the system design, although it will likely have slightly reduced performance over the hard core. In addition, ARM cores have been verified for different foundries as well as the customer's fabrication facility. This affords the customer the future flexibility of moving fabrication out of an in-house fabrication facility into a pure-play foundry, with the knowledge that the core they are using has been qualified on the foundries' processes. This reduces the risk of a customer purchasing an ARM core over a competitor's product, because the increased flexibility does not constrain future fabrication decisions. The wide variety of methods of delivery allows ARM to target highly specific customer types within their market niches.
- 6.4.35 In a similar manner, TTPCom, which provides the intellectual property for mobile telephone *systems* (rather than for the processor), initially optimised its designs for a particular core for specific customers, forcing them either to purchase the particular core, or accept sub-optimal performance. However, the company also realised it could develop superior competitive advantage by increasing customer flexibility through optimising the system design for a multitude of different cores.

⁶⁸ A hard core license is fixed for a particular implementation process (i.e. whether the core is fabricated using 90nm, 130nm, 300nm technology). A soft core allows the customer to choose amongst a number of different implementation technologies. An architectural license allows the customer to create their own implementation technology.

- 6.4.36 In addition to increasing the flexibility of their customers, companies must themselves be flexible and adaptable in fast moving markets where customers' outsourcing preferences can change rapidly. Where companies are in niche markets, particularly fabless companies and contract design houses, the need to be flexible and adaptable is crucial. The disruptive nature of the technologies in the electronics market means that market power can quickly shift away from incumbents.
- 6.4.37 Market research is one of the crucial enablers of flexibility and adaptability in electronics design because of the technological complexity of products and services. It tends to require examination not just of the demand facing their customers, but also their customer's customers and final consumers. Understanding future trends in these markets allows companies to target areas that will generate the greatest future return.

*Collaboration*⁶⁹

*"Collaboration is central to our competitiveness"*⁷⁰

*"Informal collaboration is good ... the more people you can have in a region where it is easy to get together and talk, the better"*⁷¹

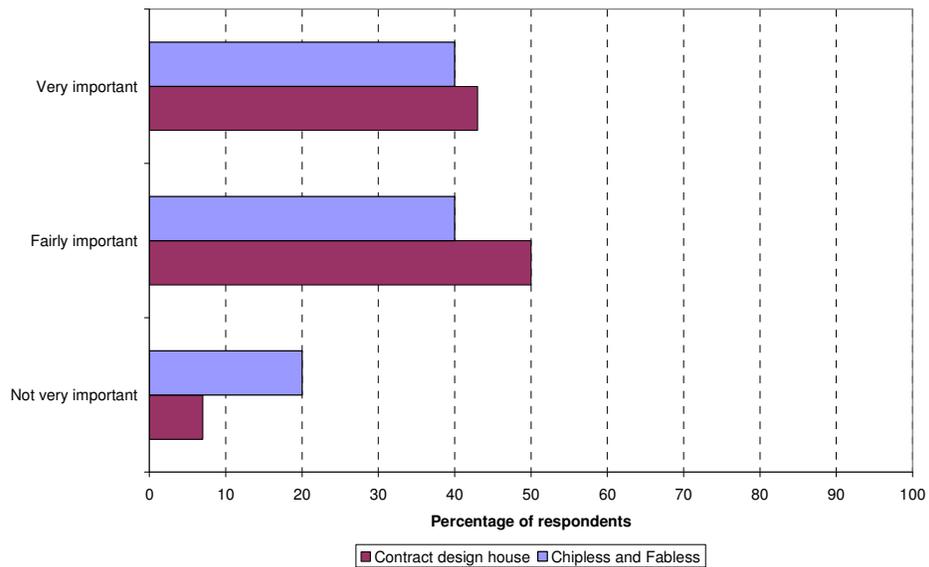
- 6.4.38 The survey provided some evidence of the importance of collaboration for a company's competitive advantage (see Figure 6.12). 40% of respondents in the fabless and chipless sectors said that collaboration is very important for competitiveness, while a further 40% considered it was fairly important. In the contract design house sector, the figures were 43% and 50% respectively.

⁶⁹ Collaboration has been defined in this report as the active engagement of the two parties in the design process of the product or service.

⁷⁰ Interview with a senior executive at a leading contract design house

⁷¹ Interview with a senior executive at a leading fabless company

Figure 6.12 Importance of collaboration for a company's competitive advantage in their main market segment.



Source: PACEC Survey

Question: How important is collaboration for your competitive advantage in your main market segment?

Number of respondents: 19

6.4.39 Collaboration can occur for a number of reasons. The following emerged as the most important for the fables and chipless sectors:

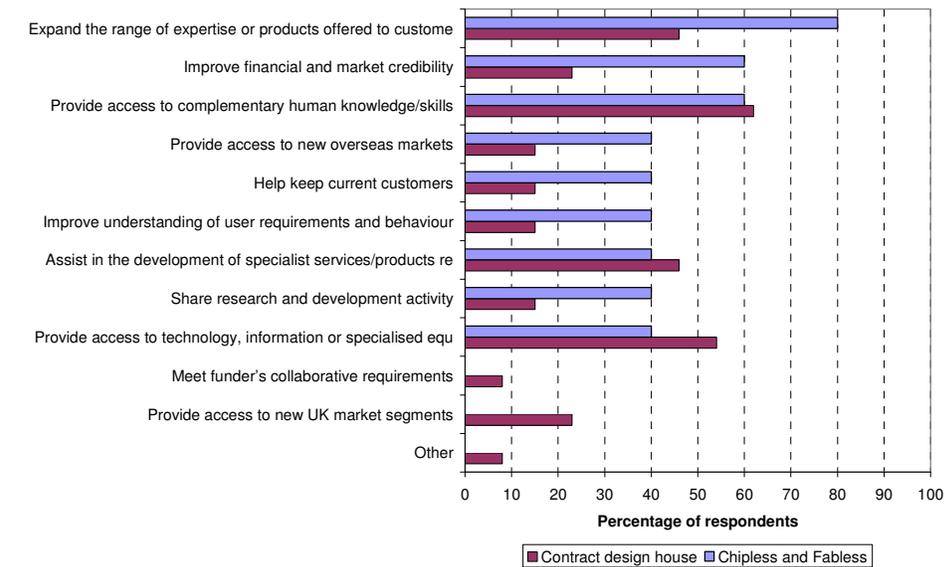
- Expansion of the range of expertise or products offered to customers
- Access to complementary human knowledge/skills
- Improved financial and market credibility
- Access to technology, information or specialised equipment
- Sharing research and development activity
- Assisting in the development of specialist services/products
- Improved understanding of user requirements and behaviour
- Keeping current customers
- Accessing new overseas markets.

In the contract design house sector, the most important reasons for collaborating in order to secure the company's competitive advantage were:

- Accessing complementary human knowledge/skills
- Accessing technology, information or specialised equipment
- Expanding the range of expertise or products offered to customers
- Assisting in the development of specialist services/products required by customers.

6.4.40 Collaboration can appear in many guises. It may be through a *formal* market relationship, formalised by the exchange of fees (involving active involvement by both parties rather than a pure sub-contracting relationship), or it can be *informal*, whereby parties exchange knowledge outside the market mechanisms.

Figure 6.13 Importance of the reasons for collaboration in affecting a company's competitive advantage



Percentage of very significant or crucial responses

Source: PACEC Survey

Notes:

Question: What are the main reasons for collaboration in your main market segment? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)

Number of respondents: 18

Formal collaboration

6.4.41 The case studies suggested that the reasons for collaboration and its importance differ between new start-ups and established companies. If the start-up does not already 'own' the technological expertise required, it can collaborate with incumbent technology providers. For example, when Frontier Silicon entered the market, one of its investors was Imagination Technologies, a successful UK chipless company. Imagination Technologies provided the initial IP for the cores used by Frontier Silicon while it developed its own IP, thus partly overcoming both the technological and reputation barriers to entry (customers would know that the core came from a reputable source, and it would be 'known-to-work'). In addition to the initial financing, Frontier Silicon and Imagination Technologies collaborated closely on products. According to Anthony Sethill, CEO of Frontier Silicon⁷²

"Partnership with Imagination has enabled Frontier Silicon to grow very rapidly and as part of a strategic partnership we have now secured our access to future generations of Imagination's market leading technology. We have also put in place a joint development programme for the next generation digital radio/audio [integrated circuits] between the companies."

⁷² Quote and subsequent information about the collaborative relationship obtained from an Imagination Technology press release (13th October 2003), "Imagination Technologies and Frontier Silicon Extend Strategic Partnership".

This highly collaborative partnership allowed Frontier Silicon rapid access to the latest processor technology. This, the reputation of its founders, and their contacts, won initial customers for its revolutionary digital audio and mobile TV products, resulting in 80% of the market for digital audio IC's and modules.

Imagination Technologies also benefits from the collaboration as an investor in Frontier Silicon, and licensor of IP to Frontier Silicon. By **investing in its partner's success**, Imagination Technologies is able to secure future markets for its intellectual property and build its reputation for delivering quality intellectual property.

- 6.4.42 A relatively new fabless start-up noted that close collaboration can improve the time to market. Beating the competition to market in very fast moving segments is extremely important because it gives the firm some control over the development of technology and standards, and enables it to capture the highest value added before it is eroded away by competition. The interviewee noted that close collaboration between three crucial partners was required to achieve this competitive advantage: end-user brand firm, the contract manufacturer, and the technology provider. By agreeing the product and specifications, much faster product development times can be achieved.
- 6.4.43 For more mature firms in industries where many players are required to bring a product development to completion, collaboration between firms can improve the efficiency and productivity of all involved, *especially in cases where interfaces are not completely standardised and codified*. For example, an Internet search of "ARM + collaboration" yields a multitude of different collaborative ventures between ARM and fabless companies, IDM companies, EDA companies and foundries. Royal Philips Electronics and ARM collaborated to offer a complete development kit for the market leading 'Nexperia Cellular System 6120', based on the ARM9 processor. This allowed Philips to significantly reduce time-to-market by simplifying the integration of multimedia applications into mobile phones. In an industry where development cycles are ever-shortening, and the number of multimedia applications desired by consumers on their mobile phones ever-growing, being able to offer such a product is a distinct competitive advantage. It is unlikely that either Philips or ARM alone would have been able to develop such a product, given the highly complex, specialised technological expertise required. However, by collaborating, Philips could realise gains from selling such products to its customers, while ARM could realise gains by ensuring that Philips' products contained an ARM core.⁷³
- 6.4.44 By collaborating on projects, companies not only invest in the success of their partners to ensure that there will be a potential market for their own products, but can also develop significant lock-in potential by offering the collaborative product as a complete solution. In the example just described, a company wanting to buy the Philips Nexperia Cellular System *must* purchase the ARM core.

⁷³ Information obtained from a PR Newswire Europe Ltd. press release from 14th February 2005, "Philips and ARM Collaboration Cuts Time-to-Market With Nexperia Mobile Developer Kit".

- 6.4.45 Other forms of formal collaborations between ARM and foundries have led to “dramatic reductions in dynamic and leakage power,”⁷⁴ leading to improvements in power efficiency. This is considered to be “*one of the most important challenges facing the semiconductor industry, as mobile devices exploit advanced processes to deliver greater functionality and performance*”⁷⁵. The two companies were able to achieve such innovative results by leveraging their complementary expertise to produce innovative low-power design techniques. Again, it is unlikely that either company alone could have produced such results in the same time frame, underlining the importance of collaborative ventures in the world of fast-moving markets.
- 6.4.46 The previous examples describe how formal collaboration is seen as important for competitive advantage by Frontier Silicon and ARM, two market leaders in their particular niches. Interviews with other successful companies, however, suggested that formal collaboration is neither a necessary nor sufficient condition for developing lasting competitive advantage. A leading chipless company believed in forming sub-contractual partnerships rather than collaborative relationships. It claimed that for small to medium sized companies, collaboration did not work as well unless the different companies have the *same* business priorities, which is rarely the case. Nevertheless, that company is the market leader in its market niches. Similarly, a leading fabless company noted that it undertakes very little formal collaboration in the *design* of its products. Most of its ‘partnerships’ are contractual rather than collaborative. Yet this company leads its technological market niche and is highly successful. The difference in strategy for securing competitive advantage likely lies in both the legacy and the experiences of these relatively young companies to date, as well as their initial capabilities.

Informal collaboration

- 6.4.47 Most of the firms interviewed noted the presence and importance of informal collaboration. Informal collaboration occurs outside market mechanisms, and can range from ‘after-hours’ discussions about particular problems with colleagues or friends in similar fields, to mobilising contacts to gain specific knowledge.
- 6.4.48 For example, ARM has created the ‘ARM Connected Community’ network of partners, comprising leading silicon, systems, design support, software, and training providers, all of whom use ARM cores in their products⁷⁶. By providing a venue for discussion and exchange of knowledge between ARM, its customers and network partners, customers can improve the efficiency of the design of final products. Informal collaboration also helps firms develop closer relationships with customers, and better understanding of problems and product trends.

⁷⁴ ARM press release from 18th July 2006, “TSMC and ARM Collaboration Achieves Significant Power Reduction on 65nm Low Power Test Chip”.

⁷⁵ Quote by David Flynn, ARM Fellow in above press release of 18th July 2006.

⁷⁶ Information on the ARM Connected Community obtained from www.arm.com

Collaborating with universities: direct and indirect benefits of collaboration

- 6.4.49 Formal collaboration between the IDE sector and universities appears to be limited across all the sub-sectors. Companies viewed university research as a little too far from commercial readiness. The design sector tends to operate just behind the cutting-edge technological frontier, and so is not directly interested in the latest research. Companies appear to have sufficient other sources of knowledge for innovation. In the survey, no fabless or chipless respondents ranked universities or R&D centres as important sources of knowledge for innovation, and fewer than 20% of contract design houses did so. There were also significant concerns voiced over the incompatibility of priorities between companies pursuing business objectives and universities.
- 6.4.50 Only the largest companies in the sector actively pursued, or were interested in pursuing formal links with universities, and saw few direct benefits to their bottom line. Their interest stemmed from more indirect benefits, such as accessing advanced knowledge in research trends. This knowledge was of very little direct benefit to their research and development activities, but was thought to add potentially significant value to customers. By passing on such information, the company strategically positions itself as a conduit through which customers can gain knowledge of the *relevant* leading edge research. This can potentially increase the lock-in effects on customers, due to the reduced searching costs facing customers for the latest research.

Location and the problem of recruiting experienced professionals

- 6.4.51 Where to locate a company is one of the most important strategic decisions a management team must make, and one with no simple answer. They need to decide on the country, and whether to locate themselves within one of the main clusters or near customers.
- 6.4.52 This decision is even more acute because the centre of gravity of the customer base is shifting away from the US and UK, and towards a number of countries in Asia, while the manufacturing base is shifting towards Asia and Eastern Europe. Adapting to the changing location of the customer base is extremely important. However, the decision to set-up a presence in another region is not easy because location does not dominate all other determinants of competitive advantage, and companies also need to take into account the potentially high fixed costs of setting up in other regions (not just buildings and infrastructure but understanding local culture, tax codes, and developing networks).
- 6.4.53 The UK IDE sub-sectors conduct most of their work in foreign markets. They are net exporters of products and services, with the larger companies generating the majority of overseas revenues (Table 6.1). The main regional source of revenue for the fabless sector is Asia, while the chipless sector is split between the US and Asia. The contract design houses generate the highest proportion of revenue in the UK (at approximately 30%), but the US is still their largest source of revenue. The lack of

much revenue from Asian sources is due to differences in the culture of outsourcing IDE services.

Table 6.1 Source of revenue by region for selected companies in the IDE sector (%)

Company	Sub-sector	Revenue from region (%)			
		Europe	USA	Asia	Other
Cambridge Silicon Radio	Fabless	11	5	82	2
Company A	Fabless	5	6	89	0
ARC	Chipless	28	64	8	0
ARM	Chipless	14	43	43	0
TTPCom	Chipless	10 ⁽¹⁾	16	74	0
Company B	Contract design house	35 ⁽²⁾	65	0	0
Company C	Contract design house	66 ⁽³⁾	33	0	0
Company D	Contract design house	60 ⁽⁴⁾	30	10	0
Company E	Contract design house	15	75	10	
Company F	Contract design house	40	60	0	

Notes:
 1: UK = 3%, Rest of Europe = 7%
 2: UK revenue
 3: UK = ~33%, Europe = ~33%
 4: UK = 30%<50%, Western Europe = 30%>10%

Source: Company annual reports (for named companies); PACEC research for un-named companies

Locate near the customer base?

- 6.4.54 Chapter 3 described how the wider electronics industry has vertically disintegrated, with specialist firms producing the components of the electronics system, which are then integrated into a product by the system integrator.
- 6.4.55 Understanding what the real needs of the customer are is crucial for securing a competitive advantage. This requires close interaction with the customer base, end-users and other partners in the design network. Companies gain faster and easier access to customers' preferences and problems by locating near them.
- 6.4.56 The compatibility of outsourced components and modules requires that interfaces between components, modules, system and manufacturing process are precisely defined. Disruptive changes in technologies (such as the seismic shift between the PCB and the Silicon-in-Package and Silicon-on-Chip paradigms) have greatly increased the complexity of chip design and the difficulty of codification. In such cases, compatibility must be achieved through personal interaction and communication.

Panel 6.2 Successful SoC design requires close interaction

By definition, SoC design requires close interaction with the system designers, marketing people and end customers (the “set makers”). With product life cycles often as short as six months or less, systems design requirements keep changing. The protocol necessary to transmit these changes real-time to all the different design network participants is “one of the greatest unsolved problems of design management”. (Wilson, 2003: 56). Hence, proximity and face-to-face contact are important. ... An important new development in Asia is that this region not only provides important growth markets for existing electronic products and services, but also test beds and launch markets for important innovations and global standards in mobile communications and digital consumer electronics.

Interactions with foundry services are arguably the most explicitly recognised interfaces in the entire SoC flow, with well documented and automatically checkable “design rules” (Macher, Mowery and Simco, 2002). Yet, with growing complexity of SoC design, the management of the foundry interface also poses new challenges (Wilson, 2003: 62-65). A combination of new processes and drastic changes in design methodology implies that design rules need to be tweaked and stretched, ... requiring a much closer interaction between designers and process engineers.

This new interface requirement [of design-for-yield] means that ... designers must take into account the effects of fabrication process variation, which makes the design even more complex. ... An extraordinary degree of coordination is required between SoC designers, mask makers, foundries and third party SIP [semiconductor intellectual property] providers. As the world’s leading foundries are all based in Asia, this creates powerful pressures for GDN’s [global design networks] to relocate increasingly important stages of chip design to this region.

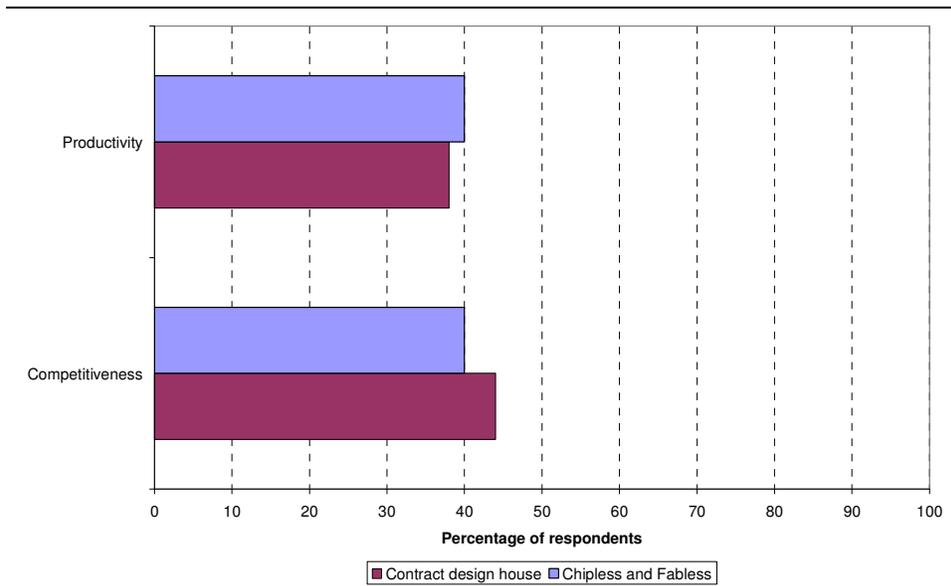
In short, chip design has become itself a highly complex technology system, where multiple communication and knowledge exchange interfaces must be managed simultaneously. While the idea of reusing SIPs is great, its implementation requires a degree of cooperation that was unthinkable even a few years ago. This is true for all the different design interfaces.

Source: Ernst (2004:21-22)

- 6.4.57 Ernst⁷⁷ provides a useful example of the increasing difficulty in locating design teams involved with the design of an SoC at distance from each other (see Panel 6.2).
- 6.4.58 The Ernst example demonstrates the importance of proximity to the customer base, and the importance of close collaboration with different network members. Many UK companies have set up sales and marketing offices near customers.
- 6.4.59 The survey provided evidence to suggest that geographic proximity to their customer base is important for the fabless, chipless and contract design house sub-sectors. Figure 6.14 shows that 40% of fabless and chipless firms, and 44% of contract design houses believe that geographical proximity to the customer base is very significant or crucial for their competitiveness. The same proportion of companies believe it very significant or crucial for their productivity.

⁷⁷ Ernst, D. (2004) “Internationalisation of Innovation: Why is Chip Design Moving to Asia?” *East-West Center Working Paper No. 64*

Figure 6.14 Importance of geographical proximity to a firm's customer base for its competitiveness and productivity



Percentage of very significant or crucial responses
 Source: PACEC Survey
 Question: How important is geographic proximity to your customers important for your competitiveness and productivity in your main market segment? (For each, please indicate importance as a score from 1-5)
 Number of respondents: 21

6.4.60 In a market with very fast product life-cycles, the ability to respond quickly is perceived as an important competitive advantage. In addition, the interviews suggested that customers prefer geographical proximity of their suppliers. This, together with the shift of the customer base to non-UK centres, suggests that companies cannot ignore the strategic problem of where to locate. However, opposing these forces are the benefits from locating within the design clusters, as well as other locational characteristics, such as the regulatory environment and the labour market.

Locate in a cluster?

6.4.61 Locating within a cluster of firms with similar or complementary capabilities, and a densely populated supply chain can facilitate the flow of knowledge between firms. This allows firms to minimise the high costs associated with difficult-to-specify interfaces which require close interaction. Locating in a cluster also facilitates both formal and informal collaboration. Clusters tend to attract specialised investors, such as venture capitalists and angel investors, making it easier to secure initial financing. They also have access to a thick labour market which reduces hiring costs.

6.4.62 The UK clusters do not rival Silicon Valley, or the rapidly emerging Shanghai cluster in either scale or scope, but it is believed that UK companies can still take advantage of the benefits of other clusters through offshore offices, joint ventures and alliances. In addition, UK companies have other advantages, such as analogue chip design skills, which could overcome locational disadvantages.

Panel 6.3 Why choose the UK for chip design?

Stan Boland, CEO of Icera, a fabless start-up that has raised \$102.5 million from venture capital and is poised on the verge of success in the mobile baseband market, was asked why he chose the Bristol cluster to set up his new company in 2002. He replied

"... Bristol is the only centre in Europe where we could assemble a crack team of full custom processor people. That is the legacy of Inmos. [The people have experience working at] STMicroelectronics or Inmos, ..., Element 14, some at DEC, some at Intel."

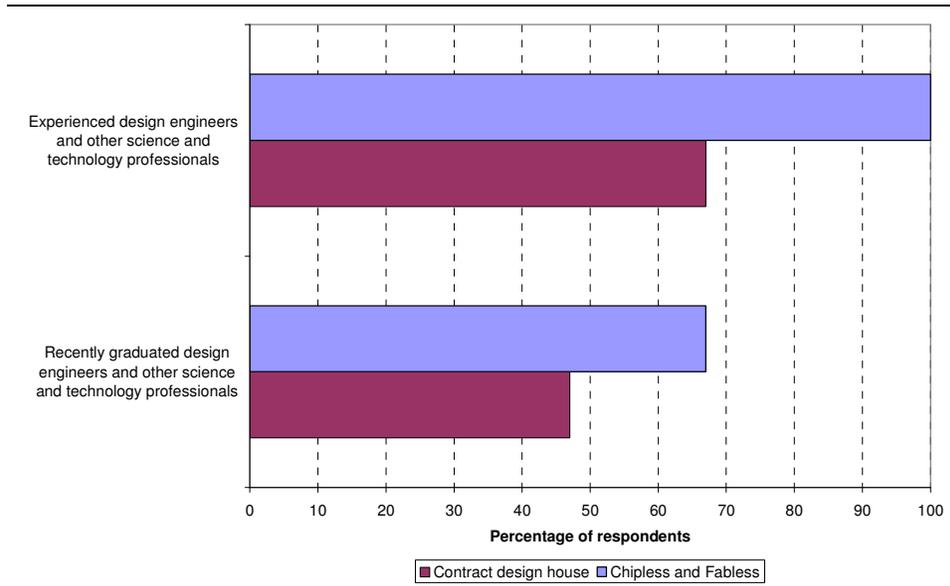
- 6.4.63 Offshore design offices have been successfully set up in overseas clusters (often by acquisition) to take advantage of complementary skills. In 2005, ARM had eleven design centres, four in the UK, one in Silicon Valley, one in Texas, one in Bangalore, and four in Western Europe. The decision about where to locate specific activities requires in-depth analysis of local advantages, codifiability, strength of communication links, and the gains from proximity. At least initially, design work both offshored and outsourced to China tends to be simple and *not time critical*.
- 6.4.64 Another mechanism that is commonplace amongst the leading fabless and chipless companies in the design sector is to embed employees within the foundries in the knowledge that design cannot completely be separated from manufacturing – the interface between the two aspects of development is still not completely codified. Through this mechanism, these companies can reduce the costs associated with operating at a distance from the manufacturers, and still gain advanced access to the latest manufacturing technology and design rules developed by the foundries.
- 6.4.65 There are costs associated with setting up offices in offshore locations, beyond the obvious fixed costs of buildings and machinery. These include:
- High costs of monitoring and developing detailed specification of work
 - Language and cultural barriers
 - Government regulation and conditions on operating in China
 - Increased cost associated with protection of intellectual property
 - Limits on the repatriation of profits.

Skills

- 6.4.66 The UK maintains competitive advantages in particular skills. A number of companies claimed that the UK has particular strengths in analogue chip design, which requires a much more creative, innovative approach to design the digital chip. In general, a common observation was that design engineers in the UK were much more creative and innovative, and is one reason why foreign companies continue to open design centres in the UK. However, there is also evidence that this particular skills advantage is dwindling.
- 6.4.67 The companies surveyed were asked to rank the difficulty in recruiting recent graduates, experienced design engineers, and other science and technology

professionals (see Figure 6.15). All fabless and chipless companies, and 67% of contract design houses indicated they found it moderately or very difficult to recruit experienced professionals. The problem of recruiting recent graduates was less of an issue.

Figure 6.15 Difficulty in recruiting design engineers, and other science and technology professionals (STPs)



Percentage of moderately difficult and very difficult responses
 Source: PACEC Survey
 Question: How difficult are you finding it to recruit... (Please enter a score from 1-4 indicating the level of difficulty)
 Number of respondents: 21

6.4.68 These results are give further support by an article in *New Electronics* (in 2005) regarding the lack of suitably qualified engineers for the niches in which the UK has a competitive edge, such as analogue design. The managing director of the electronics design consultancy Plextek noted in the article that:

“During the technology recession, a lot of averagely skilled engineers appear to have left the electronics market and found work in other markets altogether. Now the market is picking up, all people of adequate capability are hard to find.”⁷⁸

The lack of *experienced*, highly skilled professionals is a problem confronting many companies in the IDE sector. The problem is made more acute because of the lack of any major electronics OEMs in the UK where recently graduated electronics engineers can gain the necessary experience. One contract design house described how the majority of the best young candidates were of Indian and Chinese origin (about one in ten applicants were from the UK), or educated in India/China and with a few years’ experience at large contract companies in India or China. Suitably qualified engineers from the UK were hard to find.

⁷⁸ Quote by Colin Smithers in Knivett, V. “Feast or Famine?”, article in *New Electronics*, 11th July 2005.

6.4.69 An expanding fabless company argued that while China produced thousands of well-qualified, competent and very hard working graduate engineers, their competitive advantage was at the product development end of the design spectrum, which requires rapid iterations and more routine work rather than highly creative work. The company believed that the UK still maintained a competitive advantage at the product innovation end of the design spectrum. However, the industry consensus is that this advantage is being eroded as Asian contemporaries develop their design capabilities. This was seen as one of the main constraints to growth by UK design companies, resulting in many expanding companies planning to grow their overseas offices rather than their UK base.

Return migration and low cost regions

6.4.70 A major competitive disadvantage facing indigenous companies in low-cost regions at present is the retention of new and experienced professionals. A typical career path for the best electronics engineers graduating from Chinese and Indian universities begins with one of the large blue-chip companies located in China, such as Lenovo, ST Microelectronics, and Intel. They then tend to migrate to the West, where salaries are much higher. There is also supposed to be a lot of movement between companies in China, leading to large continuity problems and slower accumulation of tacit knowledge. This also leads to increased costs for UK IDE companies seeking to offshore/outsource design work to China as it becomes harder to develop networks of experienced contacts and to deal efficiently with outsourcing partners.

6.4.71 While labour mobility is a problem for the rapidly emerging Chinese electronics sector at the moment, it will almost certainly bring benefits in the future. The engineers who migrate westwards tend to work for some of the best, biggest and most innovative firms in the electronics industry. Many progress to senior management positions, while others become involved in start-ups in the global clusters. In addition, thousands of Chinese and Indian engineers are being educated at all levels in the top engineering universities in the West, and typically go on to become industry leaders.

6.4.72 This is a familiar trend. Israeli and Taiwanese engineers emigrated to the US in the 1960s and 1970s, and like Chinese and Indians today, went on to hold senior positions in industry. In the 1970s, many returned to their home countries to develop similar businesses. The return of engineers with years of experience, reputation and a network of contacts, is one of the main reasons for the rapid ascent of the Chinese and Indian electronics markets.

6.4.73 In the short term, the UK sector benefits from migration by obtaining some of the brightest engineers from China, India and other countries. In the longer term there are questions about the future supply of human capital for the UK IDE sector.

Knowledge of the system and market research

6.4.74 The increasing complexity of interfacing between different design modules has led to the prioritisation of greater collaboration and improvement in the understanding of the

wider system within the design network. This is observed in all IDE sub-sectors. Contract design houses increasingly have to understand the volume manufacturing process as well as design at the prototype stage. Chipless companies are offering services that facilitate the customisation and integration of the core into the wider system, and developing strong links with foundries in order to better design for the manufacturing process, while fabless companies are employing manufacturing process engineers. To gain knowledge of the final system, companies increasingly conduct detailed in-depth market research and develop collaborations and partnerships.

Is there a first mover advantage?

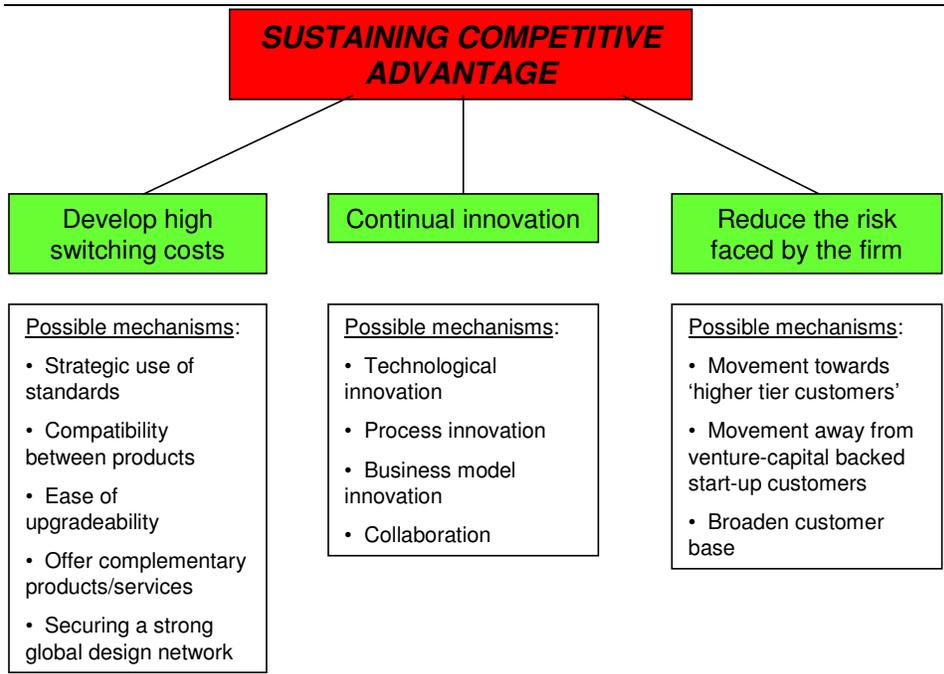
- 6.4.75 The electronics industry is thought to be characterised by global design networks in which the systems integrator (hub firm) develops close relationships with supplier firms in the network (spoke firms). Breaking into the network can be difficult, in part due to the large costs of switching suppliers of electronics components and embedded software.
- 6.4.76 Fabless and chipless companies interviewed claimed that they gained more advantage, in terms of securing their position in the global network, brand recognition and reputation, from being the first in getting their outputs into customers' new products rather than being first to develop a new technology. There are risks with new technologies for companies operating in very fast-moving markets (such as mobile telephony), who will only switch chip suppliers if substantial improvements in functionality and/or performance can be proven.
- 6.4.77 A fabless company interviewed had designed one of the earliest MP3 players (much earlier than Apple's iPod), selling to retail stores under its own (unknown) brand name, but without much success. It subsequently licensed its MP3 technology to third parties. The company believes that a critical issue for its product's inability to succeed was its own inability to develop a brand and to offer the customer a complete solution. Despite having developed some of the earliest MP3 technology, the company could not break into Apple's global design network. The UK's Wolfson Microelectronics, and the US fabless PortalPlayer were able to, and consequently flourished.
- 6.4.78 The inherent complexity in products means that being early can provide substantial competitive advantage. The way in which successive generations of products are refined and developed can be influenced, and technical expertise accumulated that others would find hard to replicate. For example, a senior executive at Cambridge Silicon Radio claimed that a company wishing to enter the Bluetooth wireless connectivity market would find it next to impossible without a substantial R&D budget, and would still lack the reputation to convince customers to switch supplier. Successive generations of Bluetooth technology have resulted in a very complex product, but the expertise is concentrated in such a small number of players, CSR, Broadcom, Texas Instruments and Phillips, such that the costs of entry are prohibitive.

The challenge of sustaining competitive advantage

6.4.79 This final section briefly considers the longer term problem of how to sustain competitive advantage once a firm has successfully entered a market niche and secured a competitive advantage.

6.4.80 No single strategy was identified, although a number of common themes emerged, focusing on developing the potential for customer lock-in by increasing the switching costs, continual innovation, and reducing the risk faced by the firm. Firms in the IDE sector appear to be able to achieve these broad strategic goals and to secure their position in their market niche through a variety of mechanisms. These are summarised in Figure 6.16.

Figure 6.16 Mechanisms for sustaining competitive advantage



Source: PACEC research, PACEC survey

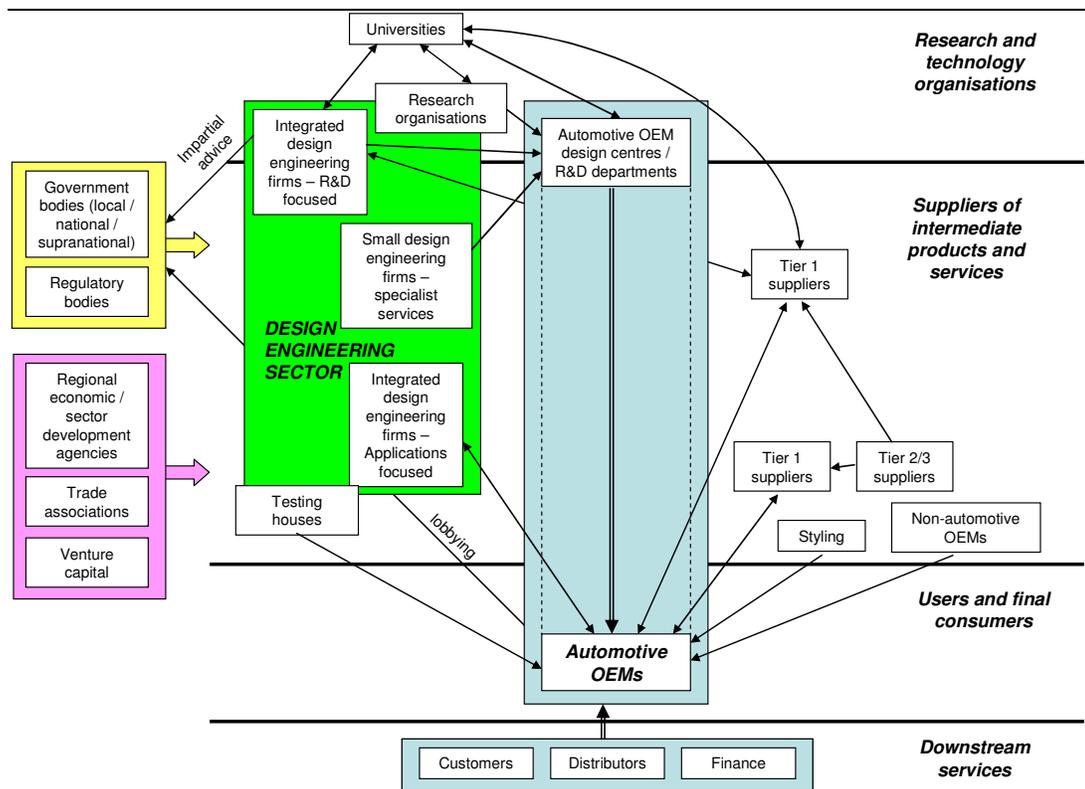
7 The independent automotive design engineering sector in the innovation system

This chapter describes the automotive innovation system and the related activities of the independent design engineering sector. It then goes on to discuss the effect of changes in the automotive industry on how innovation is organised.

7.1 The automotive innovation system

7.1.1 The automotive innovation system is highly fragmented, with activities taking place across a wide variety of organisations. These include the automotive manufactures (OEMs), component suppliers, independent design engineering companies, universities and other research and design centres. In addition, government, regulatory bodies, trade associations and other organisations influence the decisions of those engaged in the design, production and distribution of automobiles. It is also highly dynamic, with significant recent changes in the organisational and geographic location of design.

7.1.2 A simplified representation of the automotive innovation system is given in Figure 7.1. Organisations interact through a variety of mechanisms, some mediated by the market, others through joint ventures, alliances and project-based collaborations, while others are informal working relationships. Given the highly complex product at the centre of the innovation system, effective interaction and collaboration between the various organisations and firms becomes crucial.

Figure 7.1 The automotive innovation system

Source: PACEC research

The automotive manufacturer (OEM)

7.1.3 The automotive manufacturers are at the centre of the system, since they continue to carry out most product development and design internally, and also coordinate the supply of all external innovation services. They, therefore, operate in many parts of the innovation system. Many have opened design and technical centres which undertake much of the R&D into new technologies, as well as new product development.

7.1.4 The organisation of development and design activities varies significantly between the three main automotive regions (US, Europe and South East Asia). It also changes over time within each region as a result of wider trends in the auto industry.

Universities

7.1.5 Universities provide much of the fundamental ('blue-skies') research that underlies technological development in the system, sometimes in collaboration with OEMs (and to a lesser extent Tier 1s and IDE companies). Formal links between universities and the IDE sector are limited because the pace and priorities of IDE innovation activity are set by commercial realities, which do not mesh easily with academic activity. However, the IDE sector benefits indirectly from academic research. Most of these highly innovative companies attend conferences, follow the academic research

literature, and spend time investigating how to exploit new ideas. Some have long-standing relationships with particular engineering departments through PhD support, research programmes, co-operation on taught programmes, and recruitment.

The supplier network

- 7.1.6 The automotive supplier network is large and diverse. Tier 1 suppliers serve OEMs directly, and lower tiers serve the OEMs through the Tier 1s⁷⁹.
- 7.1.7 Tier 1 suppliers produce complete systems, e.g. fuel injection, chassis, power train control, electronics, steering, exhaust, suspension, seats and doors, as well as modules and individual components.
- 7.1.8 Four main types of suppliers are emerging (Jürgens, 2003). Most have advanced design engineering capabilities, and some compete with the UK auto IDE sector:
- Component specialists requiring high technological capabilities (e.g. KS, Mahle, GKN and Meritor)
 - Systems and module specialists (e.g. Visteon, Lear, Johnson Controls and Bosch)
 - Product development specialists (e.g. EDAG Engineering, AVL, Bertrandt and Rücker)
 - Assembly specialists (e.g. Karmann, Bertone, Matra, Pininfarina, Magna and Valmet).
- 7.1.9 Some Tier 1 suppliers have an innovation as well as a manufacturing culture. For example, large electronics component manufacturers such as Bosch have well developed product development and design engineering capabilities.

The design engineering sector

- 7.1.10 The independent design engineering sector operates primarily within the supplier network in the system. However, the larger companies often have links with the wider innovation community such as universities. They also tend to have a closer relationship with government, and may advise on technology, investment and regulation issues. Design companies may also supply innovation services to other industries, such as aerospace & defence, mechanical engineering, and other transport.
- 7.1.11 Design engineering firms tend to be either relatively large integrated operations, such as Ricardo (UK), AVL (Austria), FEV (Germany) and Southwest Research Institute, SwR (USA); or small, specialised service providers. The first group is dominated by European firms, offering complete sets of capabilities for an entire module or system, with some offering complete vehicle capabilities⁸⁰. Some are R&D intensive in order

⁷⁹ Tier 0.5 was a term used to describe the in-house component companies that were spun off OEMs as they restructured (e.g. Delphi from GM and Visteon from Ford). At the time, the industry thought that these companies would provide a wide-ranging capability in many elements of the vehicle. However, cost and other competitive pressures have resulted in large degrees of specialisation making the Tier 0.5 companies very similar to Tier 1 suppliers.

⁸⁰ This study doesn't investigate styling services.

to maintain their positions as leading-edge technology providers while others are more applications-oriented. The second group typically provide a small number of specialised capabilities (e.g. calibration, testing, rapid prototyping, CAD).

- 7.1.12 The IDE sector also has a varied ownership structure. Whilst many are independent, some are owned by Tier 1 suppliers and OEMs.
- 7.1.13 In addition, there are a large but unknown number of 'freelance' design engineering consultants. They typically operate through professional staffing agencies and are staffed directly into the automotive OEMs, and to a lesser extent into Tier 1s, during times of constrained capacity rather than to provide particular capabilities. Due to difficulties in determining exact numbers, they have been omitted from our analysis.

The nature of interactions in the system

- 7.1.14 The automotive innovation 'system' was hierarchical until the 1980s, with the automotive OEM leading the complete project, designing and engineering almost all parts and components. Components were both manufactured in-house and outsourced to component suppliers. Information flow between OEMs and suppliers was distinctly 'one-way', with OEMs dictating technical details, prices, quantities, billing, terms of payment etc. (Lung, 2002).
- 7.1.15 In recent years, the system has become more of a collaborative network, although the OEM remains at the hub of the system, responsible for the definition of the core architecture of the vehicle and its engineering. This came about because of (a) the increased complexity of designing components and the interfaces between parts, modules and systems; (b) the need to improve efficiency in automotive design and production, for example, by greater specialisation; and (c) the increased importance of regulation. Each requires greater sharing of information and partnership in the development process (Lung, 2002), although OEMs vary in the extent to which they pursue this model. This integration of the automotive system has been greatly facilitated by rapid advances in information and communications technology (ICT).

7.2 The activities of design engineering companies

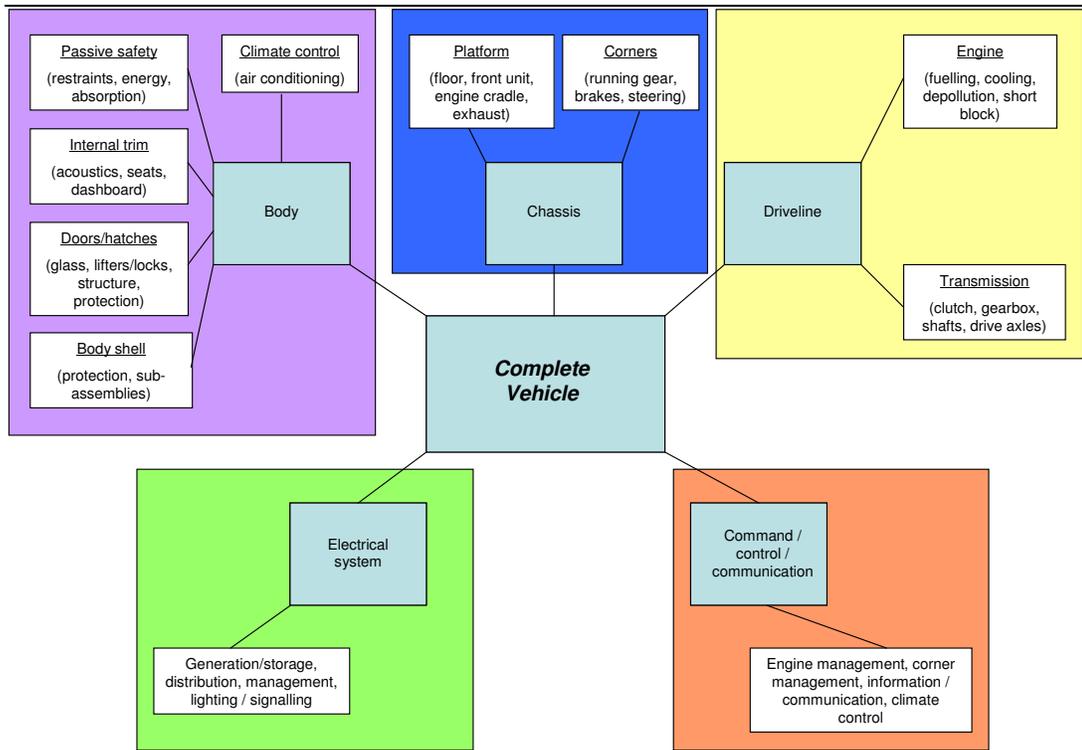
7.2.1 Design engineering companies solve OEM problems by supplying specialised design engineering services. They are fairly heterogeneous, and differentiate themselves by service range, module specialisation, technological sophistication, degree of collaboration, geographical location and sectoral diversification.

Module specialisation

7.2.2 The development of a vehicle can be broken down into systems and sub-systems (see Figure 7.2), each of which requires a range of design engineering capabilities, from conceptual design to engineering and from prototyping to testing. With the rapidly increasing complexity of the different modules and systems, the ability to seamlessly integrate the component, module or system into the wider vehicle design is becoming a crucial capability.

7.2.3 The perception of the relative importance of different modules (indicated by the large boxes in Figure 7.2) for competitive advantage differs between OEMs. Powertrain is seen by many European OEMs as the 'centre' of the vehicle around which everything else is designed. Other European and some US OEMs have a different view. These differences affect the willingness to outsource design and manufacture of a given module.

Figure 7.2 System structure of a vehicle



Sources: Maxton and Wormald (2004), Automotive Directorate publication "Automotive DE in Britain", and PACEC research
Coloured boxes indicate different modules of the vehicle

Service range

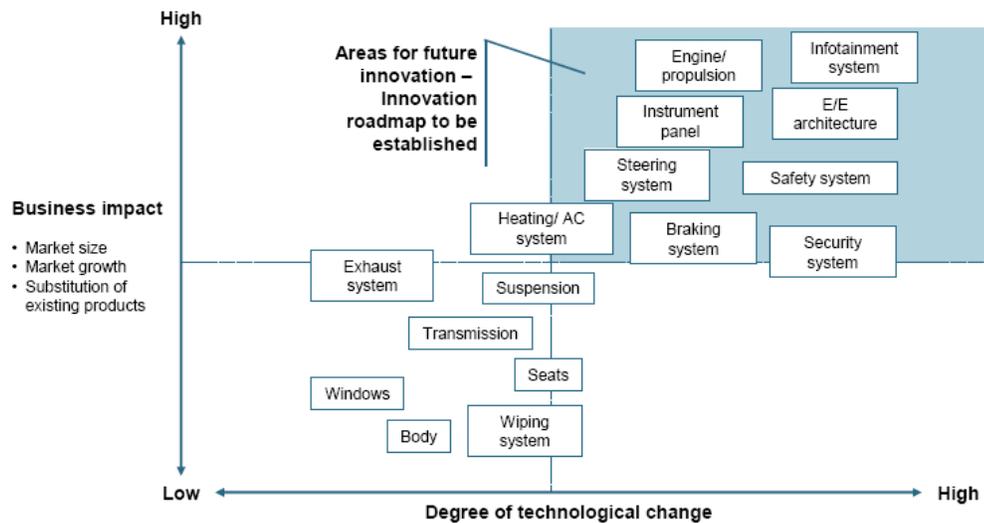
7.2.4 Design engineering companies subdivide roughly into those that offer a 'complete service' (larger integrated IDE firms), and those which are involved in part of the design process over a sub-module/sub-system (small, specialised IDE firms), although all IDE companies do some part work. Complete service could involve everything from product development to manufacturing, or the complete design of one or more entire modules or systems.

Technological sophistication

7.2.5 Modules and systems vary by their complexity and the required technological capabilities. The more complex the system, the greater the need for a high degree of collaboration with the customer and advanced capabilities in the supplier.

7.2.6 A study by Roland Berger (2001) attempted to forecast the key systems that are likely to undergo high levels of technological change and the impact this would have on the automotive system. Key systems include the engine/propulsion, infotainment systems, electrical and electronic architecture and safety systems (see Figure 7.3). Systems which experience high levels of technological change represent opportunities for IDE companies, as OEMs may not be as specialised or as nimble in keeping up with technological advance.

Figure 7.3 Pace of technological change and business impact of key systems



Source: Roland Berger (2001) "Automotive Engineering 2010: Achieving More For Less"

7.2.7 Technological capabilities which have applications outside the sector, e.g. electronics, engine design, seats, also increase DEC opportunities for sectoral diversification.

Degree of collaboration

7.2.8 The larger design engineering companies are often collaborative partners in the design and development of new products, They operate in three distinct situations, (Jürgens, 2003):

- Joint development activities, working at the OEM's engineering sites, within the framework of its cross-functional teams.
- Joint development activities, working at the IDE firm's engineering site, with visiting engineers from the OEM and from the suppliers.
- Joint development of modules and components between two or more OEM suppliers, working at the site of one of the supplier companies or at the IDE firm's site.

7.2.9 Design engineering companies typically work for a number of OEMs and suppliers at any given time, although many of these are also intense rivals. Because close interaction between IDE firms and customers is the norm, the ability to maintain total confidentiality is critical.

Geographical location

7.2.10 Customers prefer, and sometimes insist on geographical proximity of suppliers and third party design engineering firms. Proximity may take a number of forms. Customers may insist on a physical satellite office. Alternatively, they may co-locate engineers either on-site at the OEM or at the IDE firm.

- 7.2.11 Partly because of their insistence on geographical proximity, the willingness of European OEMs to outsource complete modules and systems gave the European IDE sector an initial competitive advantage over its US counterpart.
- 7.2.12 There is some evidence that the design of different modules and systems tends to cluster geographically, and that these are becoming stronger (Lung, 2002) as vehicle complexity increases and higher levels of interaction and communication are required.

Sectoral diversification

- 7.2.13 The IDE sector serves other sectors than automotive. The UK sector's specialisation in engine design has obvious relevance to motorsports. For example, Prodrive is heavily involved in rally car development and management, and Ricardo's services are also widely used throughout the motorsport sector, including contracts with Formula 1 and Indy car teams. They are also applicable to other engines, e.g. off-road vehicles, military, marine, and construction equipment. A number of UK IDE companies generate a significant share of revenues from these and other sectors.

7.3 Broad auto industry trends affecting the innovation system

7.3.1 There have been significant changes in the organisation of design and development activities in the automotive innovation system, driven by technological change (the ICT revolution), global competition and markets, regulation, and consumer preferences (Lung, 2002, MacNeill and Chanaron, 2005).

Increasing global competition

7.3.2 The past three decades have seen a great transformation of the global auto industry. Growth in global auto nominal output fell from an average 6% per annum between 1950 and 1973 to 1% per annum between 1973 and the late 1990s, and stalled completely between 1999 and 2003. Expectations of rapid growth in automotive markets in developing regions such as Latin America never materialised, but now attention is focused on China and India.

7.3.3 The US and Western Europe dominated global production until the 1960s, but by the end of the 20th Century, production in Japan had expanded massively and competition had become intense. These three areas now account for nearly 80% of global auto production.

7.3.4 Other regions are emerging: South Korea, Malaysia, Russia, Brazil and Romania all boast automotive industries. The most recent to emerge are India, China and Iran. Maxton and Wormald (2004) cite a study by Autopolis which claims that growth in the global automotive industry will not be in the original automotive regions of the US and Europe, but rather in Asia, Eastern Europe and South and Central America. They forecast Asia will have become the largest automotive region in the world by 2020.

7.3.5 Maxton and Wormald (2004)'s classification of countries with automotive industries (Figure 7.4) gives a useful categorisation of the regional growth prospects of the global auto industry.

Figure 7.4 Global positions of national automotive systems

<p><u>Core</u></p> <ul style="list-style-type: none"> • US – 16.7 m • Japan – 10.2 m • Germany – 5.5 m • France – 3.7 m 	<p><u>Autarchy</u></p> <ul style="list-style-type: none"> • China – 2.9 m • India – 0.9 m • Russia – 1.3 m • Iran – 0.3 m • Malaysia – 0.4 m • South Korea – 2.6 m
<p><u>Peripheral</u></p> <ul style="list-style-type: none"> • Spain – 2.8 m • Belgium – 1.1 m • Poland – 0.3 m • Czech Republic – 0.5 m • Hungary – 0.1 m • Turkey – 0.3 m • Canada – 2.6 m • Brazil – 1.7 m • Mexico – 1.8 m • Argentina – 0.3 m 	<p><u>Networked in</u></p> <ul style="list-style-type: none"> • UK – 1.8 m • Italy – 1.4 m • Sweden – 0.5 m • Thailand – 0.5 m • Australia – 0.4 m • South Africa – 0.4 m

Source: Maxton and Wormald (2004)
 Values are the country's production of automobiles

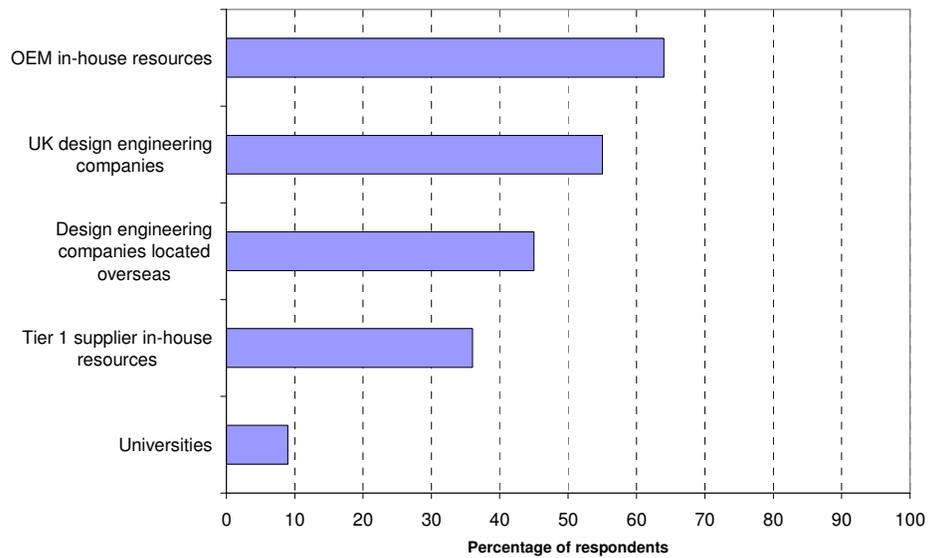
- 7.3.6 Core countries have the scale, ownership and technological leadership to sustain a complete automotive industry.
- 7.3.7 Peripheral countries, clustered around the core countries, aim to become integrated within the major automotive regions, rather than develop their own complete automotive industry.
- 7.3.8 Autarchic countries are trying to develop their own complete automotive industry. China, and to a lesser extent India, are most likely to succeed, with Russia and Iran much more uncertain. The remaining autarchic countries have largely failed in their attempts to develop into a core automotive region. Many peripheral countries were once autarchic: for example, Spain in the 1970s, although the once independent Spanish automotive sector is now completely foreign owned.
- 7.3.9 'Networked in' countries have experienced a major decline or complete collapse in their independent domestic automotive industries, but remain significantly networked into automotive industries in other regions. For example, the UK's automotive sector is now largely foreign-owned, although it has retained significant manufacturing and design capacity.
- 7.3.10 The most likely regional market to achieve the size of established markets is China. The demand for cars is expected to grow strongly over the next decade, and make China the dominant vehicle market in Asia. However, Autopolis forecast that Asia will not become the largest automotive region until at least 2020 (Maxton and Wormald, 2004).

- 7.3.11 Most large OEMs have strategies for accessing this market, mainly through partnerships with Chinese OEMs such as Shanghai Auto Industry Corporation (SAIC) and First Auto Works (FAW). However, there are considerable risks. The Chinese government's plans to develop a strong independent domestic automotive industry, and ambivalence about the protection of proprietary technology (Maxton and Wormald, 2004) mean that China may not turn out to be the expected goldrush.

Evolving competitors in the design engineering sector

- 7.3.12 The sources of competition confronting the UK IDE sector are both spatially and temporally dynamic, with the importance of different sources changing over time, and new regions emerging as the automotive innovation system shifts.
- 7.3.13 The main source of competition is the in-house design engineering teams of the OEMs that would undertake the project were it not being outsourced (Figure 7.5). As the outsourcing strategies of the OEMs change in response to the different demand and supply pressures outlined earlier, the intensity of competition with the in-house resources changes. During downturns, OEMs may downsize their internal capabilities to reduce costs. This reduction means that the IDE firms become more competitive than the in-house team, in terms of capabilities. This, in turn, means that for a period of time the intensity of competition faced by the IDE firms from OEM in-house design engineering teams decreases.
- 7.3.14 Competition from within the IDE sector, both domestic and foreign, is the next major source of competition. The interviews show that the top-tier firms are primarily exposed to overseas competition, while the smaller IDE firms primarily serving local customers mainly compete with UK-based firms. The major overseas top-tier competitors include AVL in Austria, FEV in Germany and Southwest Research in the USA. Lack of publicly available data for these private companies prevented a quantitative comparison of their performance with UK IDE firms.

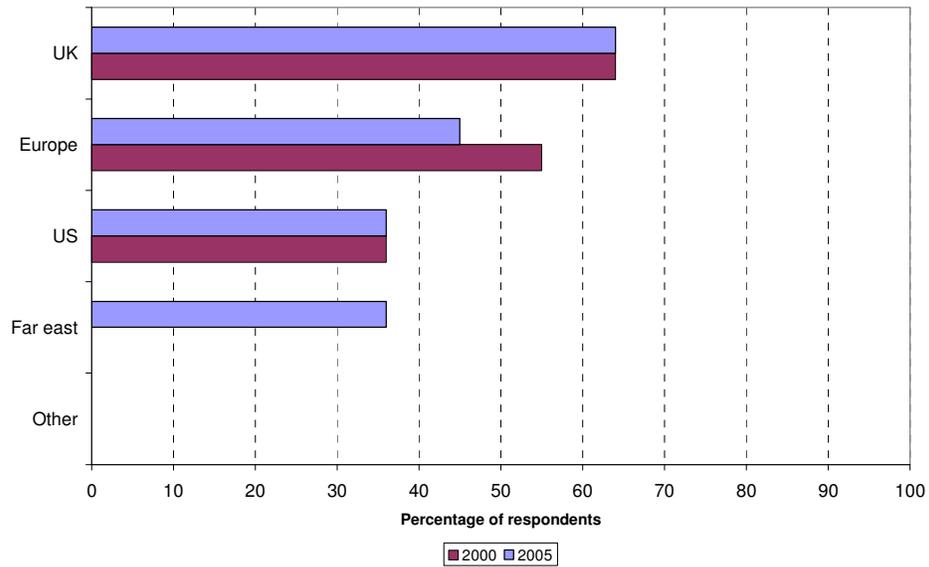
Figure 7.5 Key competitors



Percentage of respondents ranking competitor type as very important or critical
Source: PACEC Survey
Question: Who are the main competitors for your services in your main market segment? (Please select as many as apply and score each from 1-5 in order of importance)
Number of respondents: 11

7.3.15 The serious competitors facing UK IDE firms are mainly located in the UK and the other key global automotive regions (US and Europe) while the Far East is rising rapidly in importance as indigenous capabilities develop (Figure 7.6). The main US competitor to the top tier UK IDE firms is located in San Antonio, Texas, rather than in the main American automotive cluster of Detroit. However, while these companies have their headquarters in particular countries, they all have offshore locations in the main automotive regions to facilitate access to customers, skills and low cost resources (this will be discussed further in Chapter 9).

Figure 7.6 Location of serious competitors



Percentage of respondents citing competitors in particular location as very important or crucial
 Source: PACEC survey
 Question: Where are serious competitors located in your main market segment and how has this changed?
 (Please select as many as apply and score each from 1-5 in order of importance)
 Number of respondents: 11

7.3.16 Firms in the UK IDE sector face, on average, six competitors in their main market segments (Table 7.1), depending on their position within the sector and market niche. The smaller companies in the sector that carry out the more routine types of work tend to face more competition (both domestic and overseas).

Table 7.1 Number of serious competitors in main market segments

	Number of competitors
Mean	6.4
Median	5
Minimum	2
Maximum	10

Source: PACEC survey
 Question: How many firms do you regard as serious competitors?
 Number of respondents: 11

7.3.17 Many firms in the UK IDE sector experienced a squeeze on profit margins during the period 2000-2004, although many have since recovered or are recovering (see Chapter 8). The squeeze was in part due to intensifying competition amongst existing companies for the limited number of customers who, in turn, had tightened their design engineering outsourcing budgets.

Changes in the regulatory environment

7.3.18 Legislation and standards imposed by governments and regulatory bodies can have a major impact on auto technologies, and are primary drivers of technological change and outsourcing by OEMs to design engineering firms.

- 7.3.19 Emissions standards, recycling legislation, the phasing out of hazardous materials, and safety regulations all have implications for the design of vehicles. OEMs have sought help in meeting new standards from specialist design engineering firms, universities and other research organisations. A large proportion of OEMs' total R&D budget is dedicated to improving engine emissions performance.
- 7.3.20 An example of emissions legislation is the European EURO IV standards which cover the emission of CO, NO_x and hydrocarbon particulates for both diesel and petrol engines. CO₂ is not covered by the legislation although there has been a voluntary agreement by OEMs to develop technology which will cut CO₂ emissions.
- 7.3.21 The EU End of Life Vehicle (ELV) Directorate requires member states to recycle or recover ELVs and components, and to phase out specific hazardous substances. Both have an impact on the development of new vehicles (MacNeill and Chanaron, 2005), stimulating the design of vehicles for minimum 'End of Life' cost. The phasing out of hazardous materials affects the design of vehicles through the search for and design with new materials.

Changing consumer preferences

- 7.3.22 'Discerning, quality and fashion-conscious automotive markets'⁸¹ have led to more complex and sophisticated technologies, a proliferation of new models and features, and larger product development costs.⁸² At the same time product life cycles have declined from an average seven and a half years in the 1970s to four to five years by 2000, and continue to shrink (Holweg and Pil, 2004).
- 7.3.23 OEMs are responding by applying mass customisation techniques to vehicle design, whereby cars are based on a particular platform, but with different combinations of technologies, products and styles applied. There is even potential for mass market mid-range cars to be made in the 'batches of one' seen in the premium car market (MacNeill and Chanaron, 2005).
- 7.3.24 The provision of on-board electronics and telecommunications systems increasingly seen in mid-range cars as key differentiators, means that bargaining power will shift in favour of electronics suppliers and software suppliers, and away from mechanical engineers. This represents a significant challenge to those firms in the UK design engineering sector specialising in engine design, but with limited electronics and software capabilities.

⁸¹ Automotive Directorate "Automotive Design Engineering in Britain"

⁸² OEMs have had not only to expand mainstream model ranges, but also to develop a quick response to the volatile niche variants market (eg sports utility variants, cabriolets, roadsters, MPVs), and develop new concept products for increasingly important international auto shows.

7.4 The impact of industry trends on the innovation system

The response of automotive OEMs

7.4.1 OEMs in developed countries have responded to the challenges highlighted above primarily by seeking increased scale, reduced costs, and technological solutions. The main avenues have been consolidation, strategic alliances, innovation, lean manufacturing, and outsourcing; each of which has had implications for how product development and design engineering are organised.

Consolidation

7.4.2 Consolidation allows development costs to be spread over a larger number of units, thus reducing cost per vehicle. Common platforms and components for different models are being introduced to this end.

7.4.3 There were more than 270 automotive OEMs in the 1950s, which reduced to 52 during the 1960s, 30 in the 1980s, and today, just 12.⁸³ By the late 1990s, the top six automotive OEMs accounted for 75% of industry output, while the top ten were responsible for 90% (Maxton and Wormald, 2004). Some experts predict that the number of major global OEMs will fall to six, with two in each region. This appears to be already happening in Japan and the US (with the merger of the US giant Chrysler with Daimler), although Europe still boasts six major car manufacturers (MacNeill and Chanaron, 2005).

7.4.4 The consolidation in the mature automotive markets stands in contrast to the growth of OEMs in China, India and the other emerging markets. Emerging companies in these markets do not currently compete head-on with the mature-market OEMs, although they are heavily active in domestic markets. Their main priority is to upgrade their capabilities in order to first ensure future dominance in domestic markets and secondly, to facilitate access to large overseas markets.

Strategic Alliances

7.4.5 OEMs are forming alliances in order to share increasing development costs. General Motors and Fiat have formed an alliance to share platforms, engines and transmissions, while Ford and BMW have allied to share engine technology. The logic of shared platforms and components is commoditisation, which concentrates value creation at other stages of the value chain such as product development.

7.4.6 OEMs seeking to build a presence in China have been obliged to form alliances with Chinese OEMs, who face the challenges of managing rapid growth in their domestic markets, and upgrading their design and manufacturing capabilities in order to maintain their domestic position, and enter overseas markets.

⁸³ Accenture (2006) "High Performance in the Automotive Supplier Industry", presentation obtained from www.accenture.com

Lean manufacturing

- 7.4.7 In the 1990s, Western OEMs began to realise the limits of automation and central control of the manufacturing process (Fordism) in reducing inefficiency and costs, and sought efficiencies through the 'lean manufacturing' programmes successfully implemented by leading Japanese competitors such as Toyota (Maxton and Wormald, 2004:111).⁸⁴ Nelissen (2002) believes that efficiency gains by OEMs between 1990 and 2000 reduced the production time for a car from 37 hours to 24.

Outsourcing of manufacturing

- 7.4.8 The automotive industry has a long tradition of outsourcing component manufacture. Indeed with the exception of engines, the manufacture of most components in the modern car is now outsourced, including complete modules (e.g. cockpit, doors, interiors, seats) and systems (e.g. transmission, electronics, braking, steering, safety).
- 7.4.9 The outsourcing of component manufacture has made automobile production lines more streamlined and efficient. To the same end, much of the manufacture of small runs of niche vehicles is also outsourced (usually to IDE companies) to minimise the disruption of mainstream engineering processes.
- 7.4.10 Most OEMs have, or are moving to a system of 'quality supplier' networks for key components, while reducing costs by sourcing globally where feasible.

Reorganisation and outsourcing of product development and design

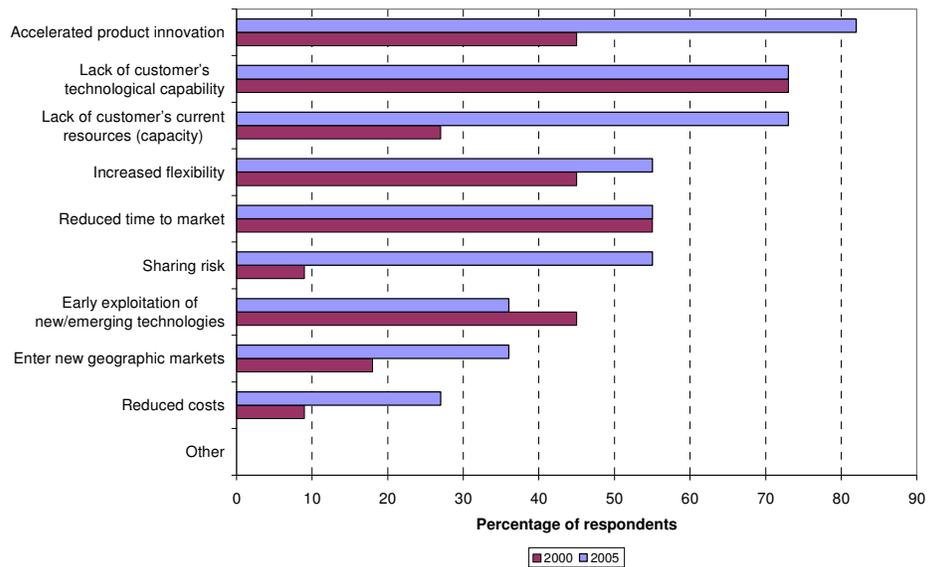
- 7.4.11 Product development and design are seen as leading elements in the response to the challenges of productivity and competitiveness, consumer demands, and regulation (MacNeill and Chanaron, 2005). This has led to increasingly sophisticated vehicles, more complex technology, and higher development costs, but little scope to increase prices (Roland and Berger, 2001).
- 7.4.12 The product development and design process has largely changed from a sequential approach to a concurrent approach. Previously, work on new products began in the product planning department, were then handed over to the design department, then to the engineering department, and so on. Product development took around seven years, and incompatibilities between departmental outputs led to frequent iterations.
- 7.4.13 The modern approach, enabled by advances in ICT, emphasises multidisciplinary teams working concurrently and connected via a central database, irrespective of location. This halved development times, reduced costs and inefficiencies, and facilitated the early involvement of third party design engineers (Maxton and Wormald, 2004). Technological advance has increased the extent to which design engineering activities can be modularised and outsourcing transactions costs

⁸⁴ MacNeill and Chanaron (2005) cite four key elements to lean manufacturing in reducing inefficiencies: (a) Human resources: better work organisation and teamwork, flexibility and devolved responsibility, (b) Capital investment: maximisation of plant utilisation rates through 'just-in-time' delivery systems, (c) Factory space: the logical flow of materials in production, (d) Materials: high 'right first time' quality and waste minimisation

reduced. In specific areas it has also led to increased complexity. This, in turn, has led to the concentration of design in 'technical centres', and early involvement by Tier 1 suppliers and design engineering companies in the definition of subsystems and modules.

- 7.4.14 At the same time, the need to improve profitability, control headcount and shed risk led some OEMs to transfer some design responsibilities to Tier 1 suppliers and independent design engineers, although this experiment has been partly reversed in the UK for reasons that are discussed later. One of the reasons for this trend was the increased importance of automotive electronics. Some IDE companies have specialised electronics capabilities, but cannot in general compete with large electronics component suppliers, such as Bosch.
- 7.4.15 OEMs have long outsourced specific design activities to IDE companies, from routine testing and CAD services to engine design and the design of entire niche vehicles.
- 7.4.16 European and Japanese OEMs very successfully operate quite different outsourcing strategies to US OEMs. Some European OEMs outsource the design of complete modules and systems, but the big three US OEMs are less willing to do this. Ford, for example, prefers to use the independent sector largely for capacity purposes and to keep core capabilities in-house.
- 7.4.17 Some OEMs need to rely on IDE companies for capacity because of past reliance on outsourcing and tight controls on employment. They also engage them for their capabilities to deal with major challenges, such as changes in technology and customer preferences (e.g. diesel), and the regulatory framework (e.g. emissions), or where internal design capabilities have been affected by downsizing. They have also outsourced part or all of the design and development of niche models, for efficiency rather than capacity or capability reasons.
- 7.4.18 The survey of automotive IDE firms conducted as part of this study revealed the perceptions of the UK IDE sector as to the reasons why their customers outsource design engineering activities and how their motives have changed over the period 2000-2005 (Figure 7.7).

Figure 7.7 Reasons for outsourcing design engineering: perceptions of the UK IDE sector



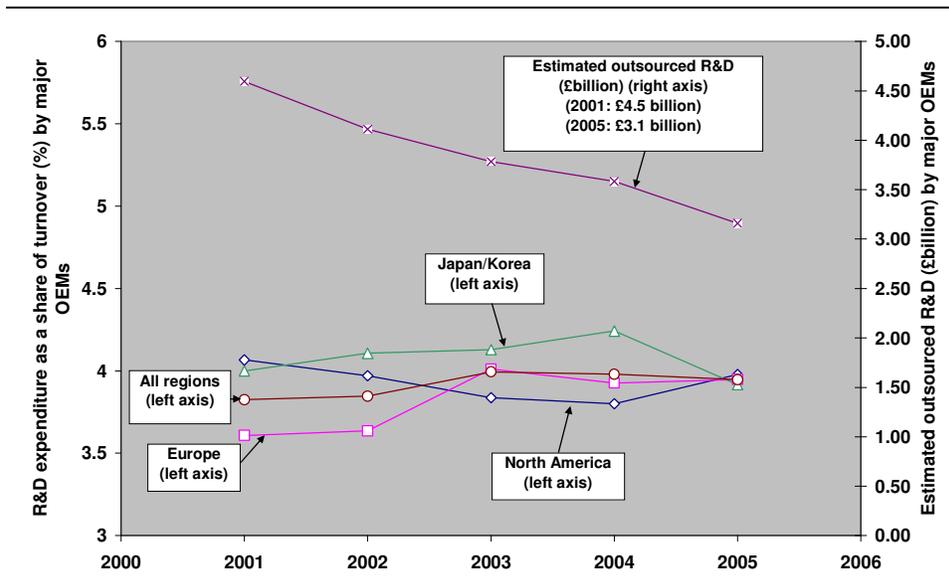
Source: PACEC survey
 Question: What are your main reasons for your customers outsourcing design activities in your main market segments and how has this changed over the last 5 years? (Please tick as many as apply in each column)
 Number of respondents: 11

7.4.19 The most common reason for outsourcing design engineering cited in 2005 was to take advantage of the ability of IDE firms to accelerate the product innovation process. This motive and that of increasing capacity and sharing development risks increased substantially over the period.

7.4.20 The amount of revenue spent by major OEMs globally on R&D remained fairly constant over the period 2000-2004, with only European OEMs showing some increase⁸⁵. However, it has been estimated that the amount of R&D outsourced has fallen significantly over the period (Figure 7.8); from approximately £4.5 billion in 2001 to £3.1 billion in 2005⁸⁶. This suggests that the potential market for the IDE community has shrunk.

⁸⁵ Based on R&D expenditure declared in the annual reports of the major OEMs.

⁸⁶ Based on PACEC research and interviews with DE companies, OEMs and industry experts.

Figure 7.8 Evolution of R&D as a share of turnover and the amount outsourced

Source: ORBIS, PACEC interviews, PACEC research

7.4.21 Most OEMs are turning to 'think globally, design locally' strategies, pursuing global engineering strategies that access global R&D, design and manufacturing resources, while at the same time localising much of the R&D for market specific products. For example, Honda and Toyota have significant R&D operations in multiple locations in the US, and undertake significant (sometimes complete) product development, design and manufacturing for the US market. OEMs now understand that regions have different preferences, due to local culture, climate and geography, and that adaptation to local conditions and resources is critical to success.⁸⁷

The impact on the supplier network

7.4.22 The trend towards the outsourcing of design and manufacturing is supposed to have led to increased technological capabilities in the supplier base (MacNeill and Chanaron, 2005). This is undoubtedly the case with regards to the longer term transfer of manufacturing and design capabilities, but more recent attempts to transfer product development and design have not been as successful.

7.4.23 Earlier outsourcing waves, such as in the early 1990s, were primarily constrained by the capacity of suppliers to host the increasing product development and design responsibilities being devolved by the OEMs. The transfer of these responsibilities, therefore, only took place slowly as and when the suppliers built up their internal capabilities, with OEMs retaining much of the design in-house.

7.4.24 This and increasing global competition led Tier 1 companies to increase their scale, product range and global coverage, primarily through consolidation. Tier 1 suppliers acquired the capabilities for whole modules via mergers and acquisitions, and sought

⁸⁷ PACEC research and interviews

to reduce the number of competitors through the buyout of rivals. They have also expanded overseas to locate near globalising OEM customers.

- 7.4.25 The number of Tier 1 suppliers fell from about 2,000 in 1990 to around 600 in 2000; and so did the total number of suppliers, from 30,000 in 1990 to 10,000 in 2000. A study by Accenture predicts that the supplier network will consolidate further to 100 Tier 1 and 4,000 total suppliers by 2010.
- 7.4.26 The UK sector is now dominated by very large firms, with top ten Tier 1 suppliers generating about £120 billion turnover in 2003 (MacNeill and Chanaron, 2005). OEM cost-cutting programmes have led to a reduction in the number of SMEs in lower tier supply networks through closure and consolidation. The remaining small component suppliers can operate successfully in niches, but others lack the innovation capabilities or the scale to satisfy the high volumes required by OEMs, a result of component standardisation.
- 7.4.27 Recent attempts by some UK OEMs to transfer design responsibilities appear to have been partly reversed. Wells and Nieuwenhuis (2003) found from their interviews with vehicle manufacturers that product development transfer was more limited than thought. A number of PACEC interviews with IDE companies confirm the impression of retreat, at least in the short term. This appears to be due to limited innovation capabilities in some areas, and reluctance to pay suppliers for their additional responsibilities.

The impact on universities

- 7.4.28 As automotive companies have become less interested in 'blue skies' research, much of the current research in university engineering departments has been somewhat more applied.

The impact on the independent design engineering sector

- 7.4.29 The independent design engineering sector received a major boost in the 1990s from changes in OEM outsourcing strategies. OEMs became more willing to outsource high value design activities, particularly Europeans, who outsourced the design of complete modules and systems.
- 7.4.30 The main impacts of this boom on the IDE sector were the development of specialised capabilities among 'top-end' IDE companies, and the development of capacity which would be exposed to future downturns in the market.
- 7.4.31 Consolidation in the auto manufacturing industry has reduced the number of customers for auto design engineering, in part offset by new entrants from the rapidly industrialising economies of Asia-Pacific and India. This has had a major effect on the UK IDE sector in the fact that Ford (including its Premier Auto Group (PAG) luxury brand division) has become the main auto industry customer. Japanese OEMs in the UK tend to locate design activities in Japan and mainland Europe.

7.5 Summary of recent changes in UK OEM outsourcing strategies⁸⁸

Driving technology development

- The drivers of change in the automotive system have profound impacts on technological development. Technology is being used to combat increased competitive pressures and consumer expectations regarding both quality and cost. It is crucial in meeting the demands for emissions, recycleability and safety regulations. It allows OEMs to add value to their vehicles to offset the squeeze on profit margins caused by price reductions. It also allows the system to meet the challenges of increasing complexity of both design and interfaces (MacNeill and Chanaron, 2005).

Outsourcing intensity

- The pendulum of OEM design engineering outsourcing strategies has swung back in favour of maintaining and fully utilising in-house capabilities.
- Design is still outsourced where there is (a) insufficient internal capacity, (b) a significant cost disadvantage to using in-house teams, (c) superior capabilities at IDE companies in specific technologies, applications and problem solving, (d) small production runs, e.g. the design and manufacturing of niche models and variants.
- OEMs would prefer outsourcing intensity to be higher, but it will be kept unusually low while budgets are tight and internal design capabilities are rebuilt.
- The design outsourcing pendulum could well swing back in future years. OEM views about which are their core activities change regularly.
- The emphasis on the capacity criterion means that outsourcing is being weighted towards part-work and contract labour.

Buyer-seller relations

- There is a major imbalance in bargaining power between customers and suppliers in the UK design engineering sector because the customer base has become highly concentrated. The shift towards using the independent sector as an overflow for part-projects has exacerbated this.
- OEM and Tier 1 cost reduction programmes are tending to shift decision making from engineering to procurement departments. IDE companies perceive the emphasis on cost rather than value added as short-sighted and damaging to the total industry.
- OEMs are experimenting with a range of contracts in pursuit of greater flexibility, risk-sharing and lower cost.
- OEMs are moving towards a 'qualifying supplier' network which will restrict opportunities for smaller design engineering companies.
- OEMs are challenging IDE companies to take advantage of the geographical shift of markets and capabilities to the Far East.
- The earlier trend to outsource design work to Tier 1 suppliers⁸⁹ is being reversed.
- Shifts in final consumer preferences away from engine performance to electronics-based functionality are less favourable to the UK sector with its

⁸⁸ The discussion about OEM behaviour inevitably focuses on Ford, the UK auto design sector's dominant customer. There will be a discussion of European and Far East OEMs later.

⁸⁹ See evidence from Roland Berger (2004).

traditional specialisation in engine design. This is partly mitigated by the new importance of emissions control.

- The shortage of work in the UK automotive sector has led design engineering companies to diversify into other sectors with some success.

8 The emergence of the UK independent design engineering sector

8.1 Introduction

8.1.1 This chapter gives an overview of the UK auto IDE sector, and provides evidence on its productivity performance and the factors that underpin this performance.

8.1.2 We focus on the auto IDE sector for three reasons. First, it provides a benchmark against which we can compare the development of the electronics IDE sector. Second, we can investigate the potential for the take up of its methods, processes and technologies in other sectors. Third, there is better availability of data for this sub-sector. However, while this was the case across companies, we were still limited to carrying out most of the analysis over the relatively short time period 2000-2004.

8.1.3 The chapter seeks to answer questions about:

- the scale and nature of the UK IDE sector serving the automotive industry
- the key activities
- the structural characteristics of the industry
- how productivity, efficiency and profitability have changed, and how it compares with similar companies overseas
- the supply side factors that affect productivity and efficiency
- the importance of company size

8.1.4 The research was based on an extensive programme of interviews with auto design companies, customers, and industry experts, a firm survey, and a review of the literature.

8.2 Overview of the UK design engineering sector

How large is the UK independent design engineering sector?

8.2.1 The UK IDE sector generated a turnover of approximately £700 million in 2005 and employed approximately 7,500⁹⁰ in around 50 companies (see Table 8.1). On face-value, the IDE sector serving the automotive industry appears fairly small compared with other established sectors, but it supplies services which are critical to the survival of the large auto industry, and it is just one example of the overall IDE sector, which serves a wide range of other sectors.

Table 8.1 Size of the IDE sector in 2005

	2005	2004
Turnover (£ millions)	700	600
Employment	7,500	7,000

Note: Excludes freelance IDE consultants.

Sources:

2004 figures: ORBIS database, PACEC estimation

2005 figures: PACEC interviews with IDE companies, PACEC estimation

What kinds of companies are engaged in design engineering activities?

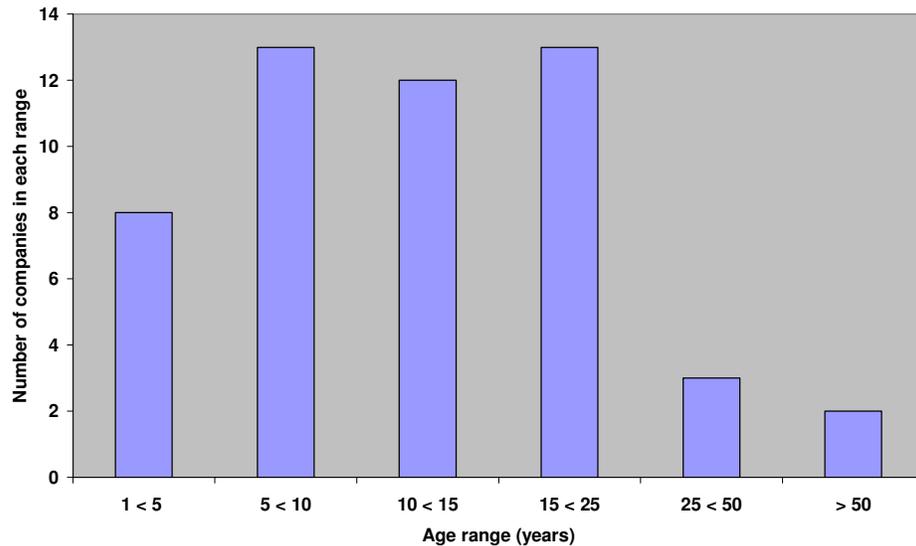
- 8.2.2 Auto design engineering activities are undertaken in-house by OEMs, by Tier 1 component suppliers, by IDE companies, and by universities.
- 8.2.3 Tier 1 component suppliers are traditionally involved in the design of components. In the late 1990s they captured a sizeable share of design engineering work outsourced from OEMs. However, much of this has subsequently been brought back 'in-house'.
- 8.2.4 Independent design engineering firms supply design engineering services to OEMs, and sometimes also provide subcontracted niche manufacturing operations. The sector has most of the capabilities possessed by OEM in-house design engineering operations, from concept design to prototyping and low volume vehicle production. In some cases, IDE firms are acknowledged to have unique capabilities. The larger IDE firms tend to offer a 'complete service' and win entire projects from OEMs. The smaller IDE firms tend to compete for smaller 'part job' contracts. These services are typically supplied on a consultancy basis, with the customer retaining the intellectual property. Fifty-two such IDE firms have been identified in the UK, with those such as Ricardo, Prodrive, Mahle Powertrain, MIRA and Lotus enjoying a significant global presence. There are also quite a few smaller consultancies.⁹¹

⁹⁰ Turnover and employment figures are PACEC estimates, based on interviews with companies in the design engineering sector and other estimation methods. The figures are lower than the estimates produced by the House of Commons Trade and Industry Committee (2004) "UK Automotive Industry in 2004: Eighth Report of Session 2003-04", *Report HC 437*. Potential reasons for the differing results focus on the exclusion of styling and freelance consultants in the PACEC estimates.

⁹¹ The study excludes styling companies.

Age distribution of the design engineering sector

- 8.2.5 The IDE sector in the UK is long-established (Figure 8.1). Ricardo can trace its roots back to 1915, and MIRA to just after WWII, while most of the larger IDE firms have been in business for at least 20 years.

Figure 8.1 Age distribution of the automotive IDE sector

Source: ORBIS, PACEC research

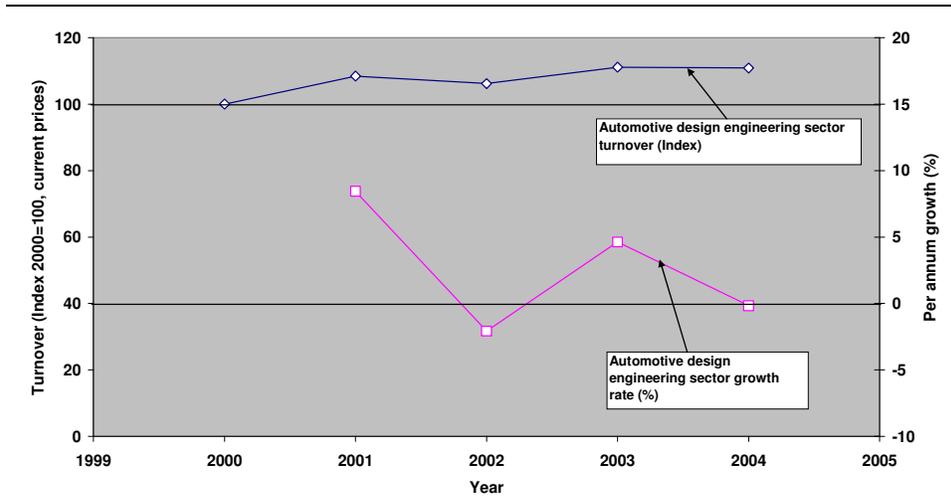
- 8.2.6 This level of survival in a small niche sector comprised of relatively small companies, coupled with a very small number of customers globally with highly constrained budgets, demonstrates a consistent competence in meeting vehicle manufacturer needs, particularly in the current difficult trading conditions. The factors underlying survival, particularly of companies at the top end of the sector will be discussed in Chapter 9.

*How has the sector evolved?****Changing turnover and employment***

- 8.2.7 In spite of consolidation in the automotive OEM and Tier 1 segments of the automotive industry, the turnover of the UK automotive IDE sector has grown, although employment has declined (Figure 8.2 and Figure 8.3). The revenue generated by the IDE sector in 2004 was about 10% greater than in 2000, a nominal average growth rate of 4% per annum over 2000-2004.
- 8.2.8 Employment in the sector appears to have fallen, with the number of employees in 2004 approximately 2% lower than in 2000. However, the IDE employment data may understate the numbers of people working in the auto IDE sector because of increased hiring of contract engineers by IDE firms. This could mean that employment in the auto IDE sector has increased rather than decreased in recent

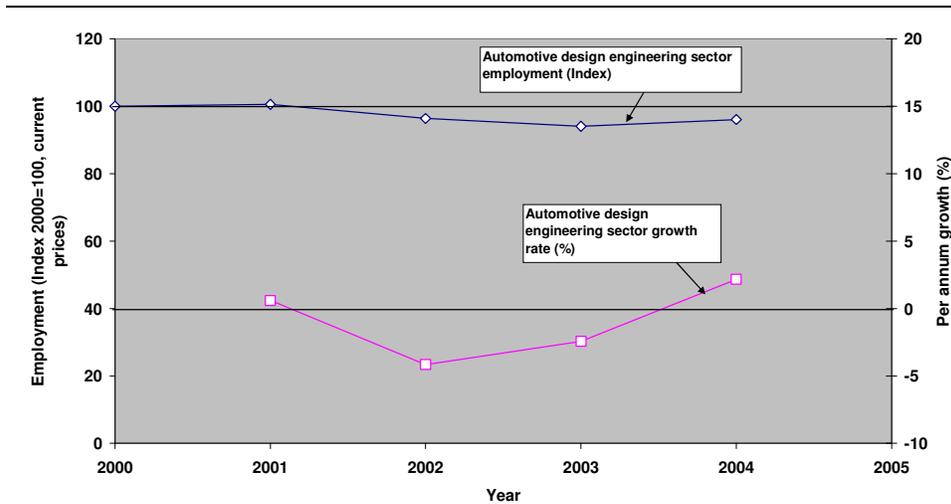
years. If true, this would suggest that IDE companies are becoming increasingly successful in winning business in other sectors and in export markets, given that UK OEM outsourcing levels declined over this period.

Figure 8.2 Evolution of turnover (index 2000=100, current prices) and per annum growth rate (%) over the period 2000-2004 for the IDE sector



Source: Data on the IDE sector: ORBIS, PACEC analysis; data on UK automotive manufacturing: Office of National Statistics: Annual Business Inquiry, published December, 12 months in arrears, obtained from the website www.autoindustry.co.uk

Figure 8.3 Evolution of employment (index 2000=100) and per annum growth rate (%) for the period 2000-2004 for the IDE sector



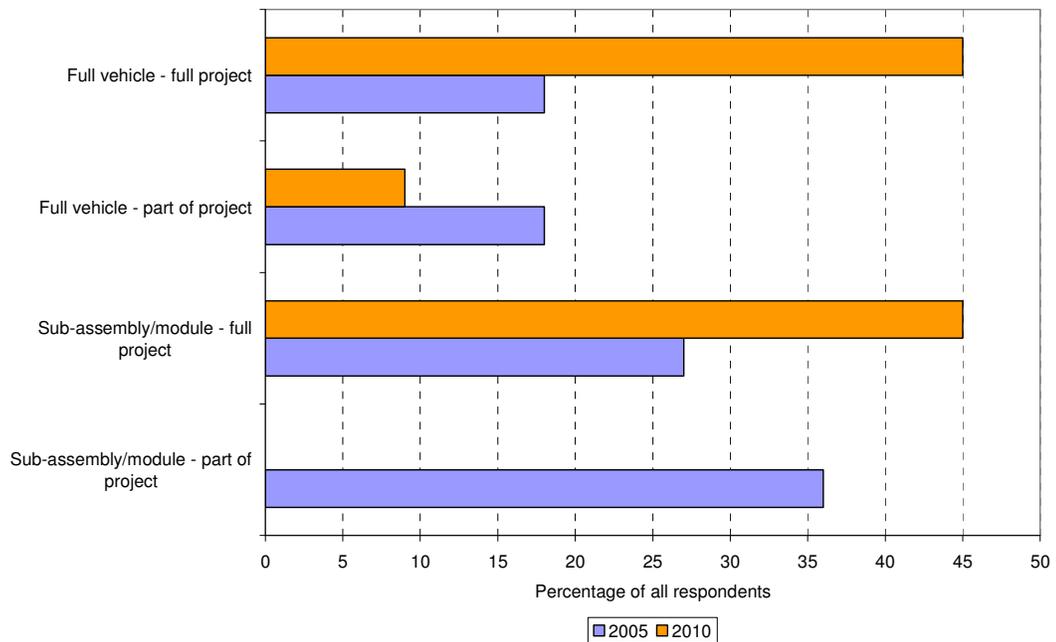
Source: Data on the IDE sector: ORBIS, PACEC analysis; data on UK automotive manufacturing: Office of National Statistics: Annual Business Inquiry, published December, 12 months in arrears, obtained from the website www.autoindustry.co.uk

The changing scope of activities

8.2.9 Although the UK IDE sector offers the full range of design capabilities, some individual companies may tend to only complete a part of a project for a sub-assembly or module, while others are given the full project for a complete sub-assembly, module, or full vehicle. While only the top tier IDE firms can offer the full solution, there is an aspiration to be able to offer this (see Figure 8.4), with 90% of respondents wishing to develop full service capabilities, up from 45% in 2005.

8.2.10 A significant part of IDE work involves supporting the production of the niche projects in the automotive industry, particularly on projects that OEMs may consider to be outside their core engineering portfolio, or which don't fit easily into plants designed for mass production. Examples of these are high performance variants of road cars, 'facelifts' and variations to existing models. This work is often full service, from concept to manufacturing. OEMs also outsource some problem solving activities, either because internal resources are tied up, insufficiently specialised, or because a quick turn around is needed.

Figure 8.4 Scope of activities offered by the IDE sector in 2005 and aspirations for 2010.



Source: PACEC survey
 Number of respondents: 11
 Question: How would you best characterise your company in terms of the scope of design activities you offer in 2005?
 (Please tick one);
 Question: In 5 years time, where would you like to be in terms of the scope of design activities you would like to offer?
 (Please tick one)

In search of new market opportunities

8.2.11 The company interviews attest to how declining margins and work from the auto industry has forced auto IDE companies to seek opportunities in other sectors and from overseas. The increase in sectoral turnover demonstrates a degree of success of such strategies over the period. This increase in turnover can be attributed to two potential sources. Firstly, an increase in automotive related revenue (likely through increases in the volume of work rather than through prices), and secondly an increase in non-automotive related revenue (Table 8.2). The increased volume derives from increased numbers of projects from overseas customers rather than from domestic customers as the focus of the wider automotive industry shifts eastwards. The largest gains in non-automotive work have been in aerospace and defence, where margins are perceived to be much higher than in auto. There is also growing involvement in other transport equipment, electronics, and motorsport. Explanations are discussed in the next chapter.

Table 8.2 Shifting market focus of automotive IDE companies (Mean contribution of the sector to a company's turnover)

Sector	2000	2005	2010 ⁽¹⁾
Automotive	87.8	80.5	70.9
Aerospace	6.7	8.8	10.8
Defence	5.0	10.8	13.6

Source: PACEC Survey

Notes:

(1): Expected value based on the respondent's perception of their firm's activities in 2010.

Question: How has the breakdown of turnover changed / do you expect it to change between industries you serve? (Please give details)

8.2.12 IDE companies are pursuing different sectoral diversification strategies, a fact that is not obvious from Table 8.2. One of the companies interviewed agreed that the proportion of revenues from auto-related work had declined from 100% a few years' ago to approximately 50% today. Another noted that while most of their work was still in auto, work in the marine, off-highway vehicles, industrial plant and aero sectors was becoming increasingly important. A third claimed that the proportion of aerospace work was increasing rapidly. In contrast, a number of firms (particularly the top-tier IDE firms) maintained that they expected to increase work for the automotive sector.

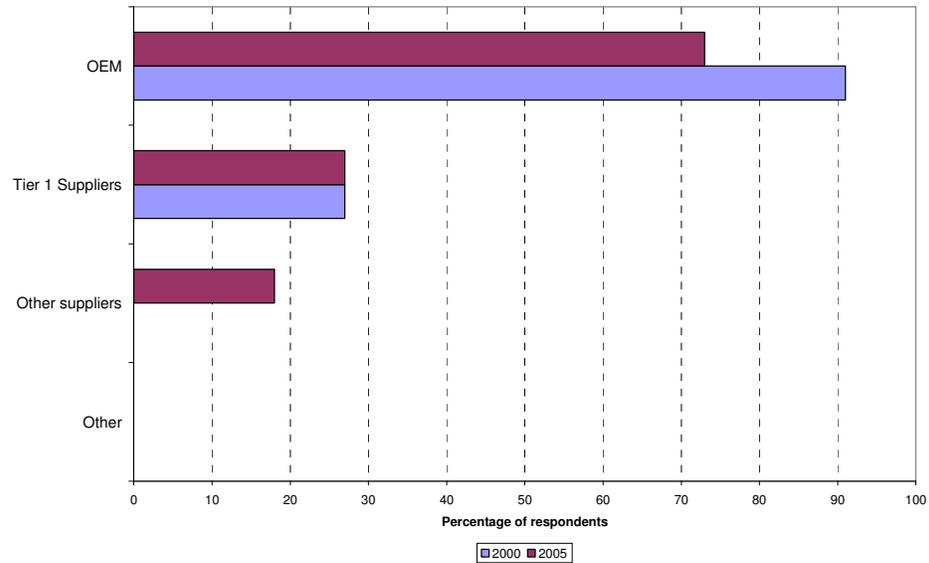
8.2.13 Despite the perceived attraction of economies of scope from applying the capabilities developed in the automotive IDE sector to other sectors, and to the higher margins in other industries, there are many barriers to entering them. Firstly, the automotive-focused firms are unlikely have a reputation or a contacts-network in the new industry, and will be faced with a (potentially significantly) different working culture.

The evolving target customer base

8.2.14 The primary target customer for the IDE sector is the OEM, with 73% of respondents in the survey of firms citing them as very significant or crucial, compared with only 27% citing Tier 1 suppliers. However, the focus on OEMs decreased over the period

2000-2005 (see Figure 8.5), probably due to the contraction and turmoil among automotive OEMs, coupled with the shifting of design into suppliers in other sectors.

Figure 8.5 Main types of customers



Type of customer ranked according to importance to their business
 Source: PACEC survey
 Number of respondents: 11

Export orientation of the design engineering sector

8.2.15 The IDE sector is highly export-oriented, with about 70% of turnover derived from exports⁹². Export intensity varies with the company, market niche, and type of customer served. Most of the larger players operate in a highly global market, serving the major OEMs and Tier 1 companies wherever they are located, and deriving the majority of their turnover from exports. The smaller companies tend not to be quite as outward looking.

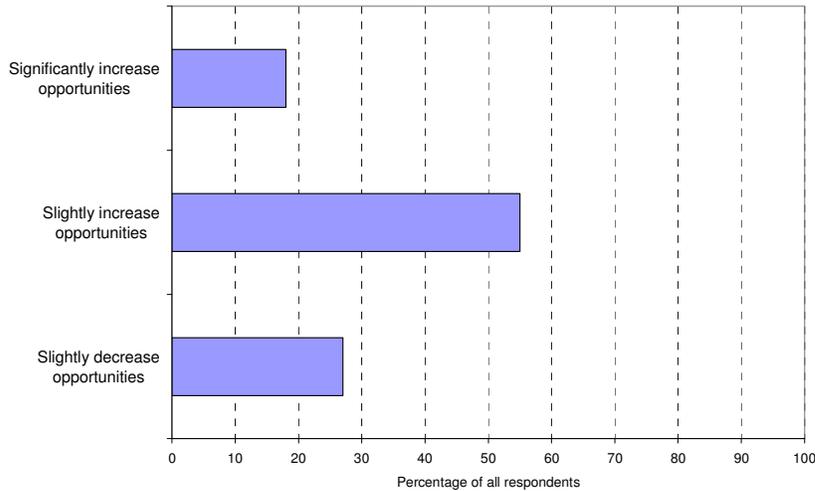
8.2.16 Many customers prefer IDE firms to operate overseas offices, both to offer proximity and to aid the integration of low cost local design resources. These offices carry out a range of functions, from sales and support, to design engineering, project management and research, depending on the size of IDE companies and identity of the customer. These offshore locations may generate a significant share of total turnover, with much of the work destined for the local market. However, while some work is carried out locally, the more complex tasks tend to be sent back to the home country.

⁹² House of Commons Trade and Industry Committee (2004) "UK Automotive Industry in 2004", Eighth report of the session 2003-2004, Report HC437

Increasing specialisation / modularisation in the automotive industry

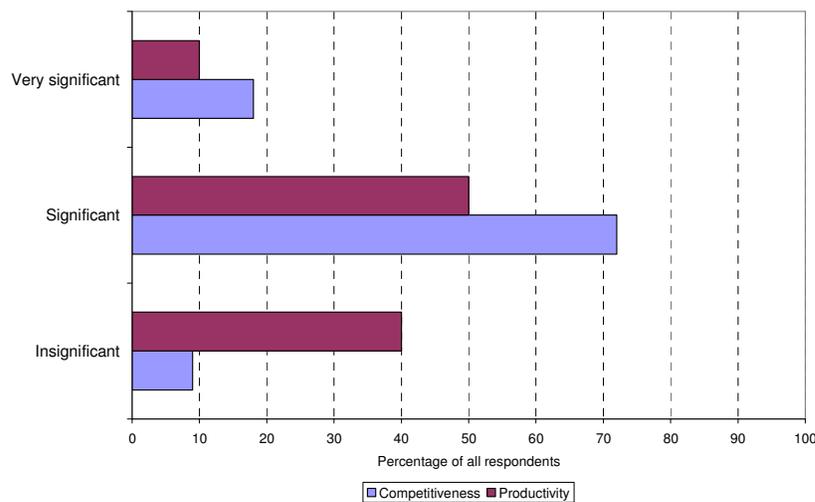
8.2.17 All survey respondents agree that there is increased specialisation and modularisation in the IDE sector. The survey revealed that 73% of firms believed that this would result in increased opportunities for their firm, with only 27% saying it would slightly decrease their opportunities (Figure 8.6). These changes were thought to have a greater impact on firm competitiveness than productivity (Figure 8.7). They would likely improve their technical efficiency although they would unlikely experience an increase in profitability margins due to the intensity of competition.

Figure 8.6 Impact of increased specialisation / modularisation on the opportunities for the IDE sector



Source: PACEC survey
Number of respondents: 11

Figure 8.7 Impact of increased specialisation / modularisation on the firm's competitiveness and productivity



Source: PACEC survey
Number of respondents: 11 respondents for competitiveness question; 10 respondents for productivity question

Changes to the contractual relationship

8.2.18 The contractual relationship between the provider of contract design and the customer is changing. Both the survey of firms and the case study interviews revealed that there has been a small shift away from a simple fee-for-service towards a combination of an upfront fee and royalty payments based on the success of the customer’s product. This shifts part of the development risk from the customer to the IDE company (see Table 8.3), and appears to have primarily affected those providing low volume manufacturing services. If this development spreads, some firms would have to develop deeper financial reserves and possibly external finance in order to fund the design and development of a project, only realising a return after completion. The gap between top tier full service IDE firms and others would also increase considerably.

Table 8.3 Changing contractual relationship between customer and provider of contract design engineering

Contract type	2000	2005
Fee for service: fixed fee	82	91
Fee for service: cost mark-up	36	27
Performance based: fixed royalty	0	9
Performance based: variable royalty	0	9
Combination: fee for service and royalty payments	0	27
Other	9	9

Values refer to the number of companies rating each type of contract as moderately significant, very significant or crucial e.g. 91% of companies rated fee for service: fixed fee as such.

Source: PACEC Survey

Question: What is normal contractual relationship between yourself and your customers in your main market segment and how has this changed over the last 5 years? (Please select as many as apply in each column and indicate importance on a scale 1-5)

Number of respondents: 11

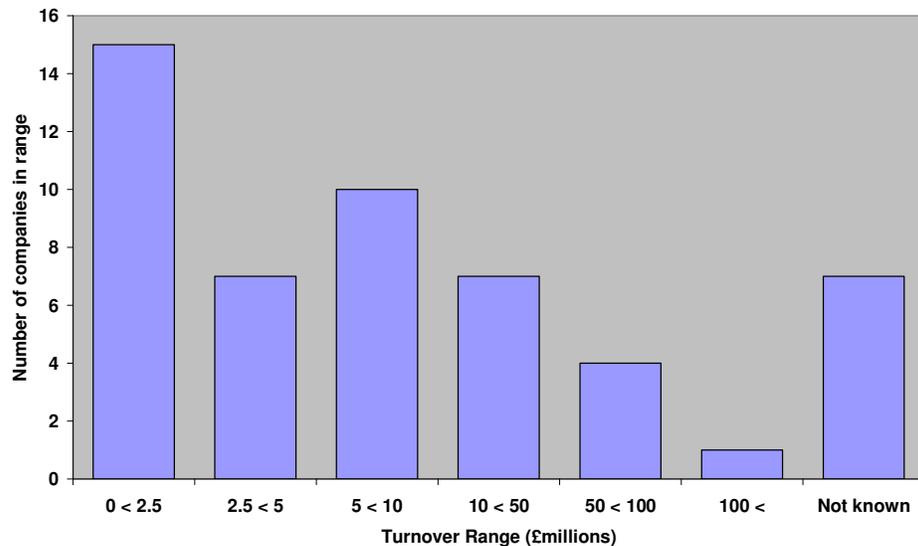
8.3 The structure of the UK independent automotive design engineering sector

8.3.1 This section focuses on the structure of the UK auto IDE sector and how it changed over the period 2000-2004. It will primarily examine its concentration and location.

8.3.2 Not including Group Lotus⁹³, the largest IDE company is Ricardo with a turnover in 2004 of some £146 million and 1,700 employees, accounting for approximately 25% of sector turnover and employment. The other large players are MIRA, Mahle Powertrain (formerly Cosworth) and Prodrive. The Welding Institute (TWI), is the fourth largest IDE company, although it serves a multitude of different industries, one of which is automotive.

8.3.3 The sectoral distribution of company turnover is shown in Figure 8.8. A third of companies have turnover of less than £2.5 million. Five have a turnover of more than £50 million with only one greater than £100 million.

Figure 8.8 Distribution of companies by size



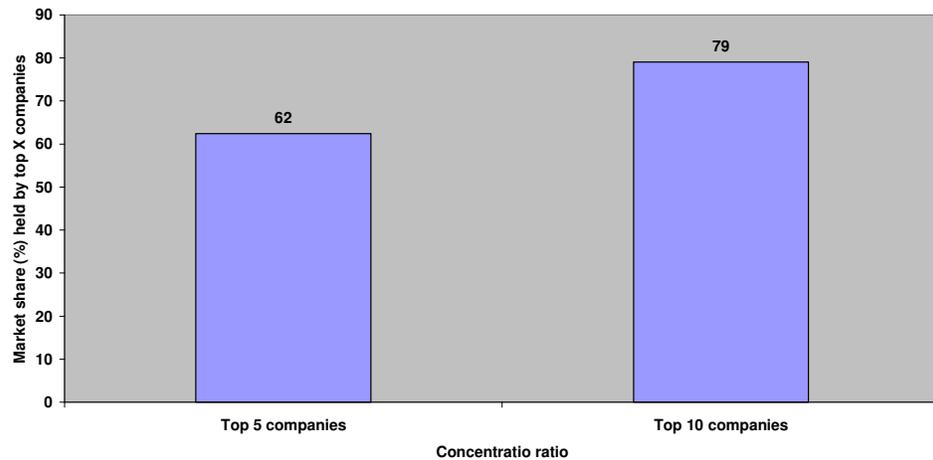
Note: The number of companies in each turnover range does not correspond to Table 8.4 due to restrictions in presenting certain companies information in that table.
Source: ORBIS, PACEC research

⁹³ Group Lotus includes both Lotus Cars and Lotus Engineering, the design engineering consultancy company within the group, but separate data on their turnover and employment is not publicly available.

How concentrated is the UK auto design engineering sector?

8.3.4 The automotive IDE sector is fairly concentrated. In 2004, the top 10 companies generated 79% (Figure 8.9). The larger companies in the sector are increasing their share of sector revenues over the period 2000-2004 (Figure 8.10)⁹⁴. This is being driven by revenue growth in the top tier IDE firms rather than the smaller companies or new entrants. Indeed, evidence from the interviews suggests that there have been few entrants into this sector in recent years.

Figure 8.9 Concentration ratios (market share (%) of the top 3, top 5 and top 10 companies)

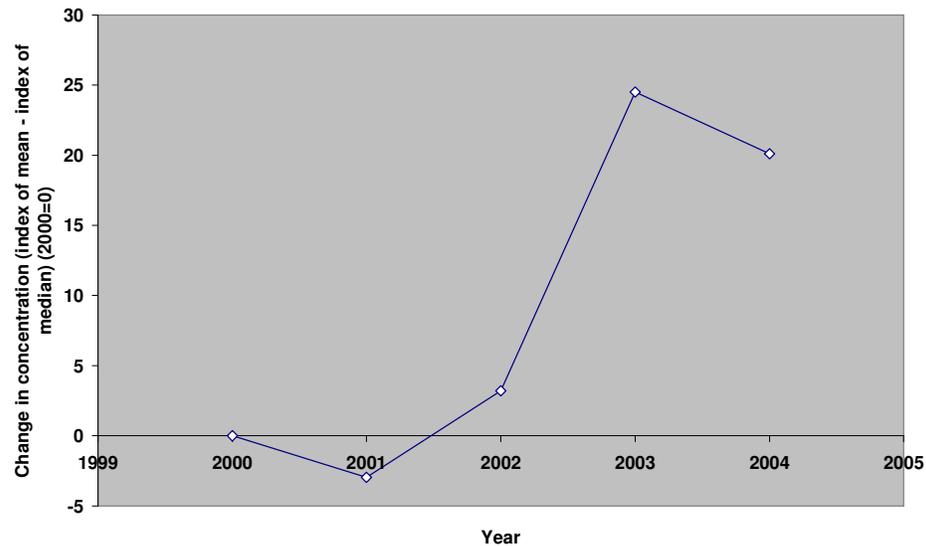


Source: ORBIS, PACEC research.

Note: Neither company level market share information nor the companies that comprise the top 3, 5 and 10 companies can be provided because particular information relating to this measure was obtained during confidential discussions with the companies in question.

Total number of companies: 51

⁹⁴ A mean that is greater than the median suggests that the share of total sectoral revenue is disproportionately captured by the larger companies in the sector. A positive divergence of the mean from the median over time suggests that the sector is becoming more concentrated.

Figure 8.10 Change in concentration of the automotive IDE sector (2000=0)

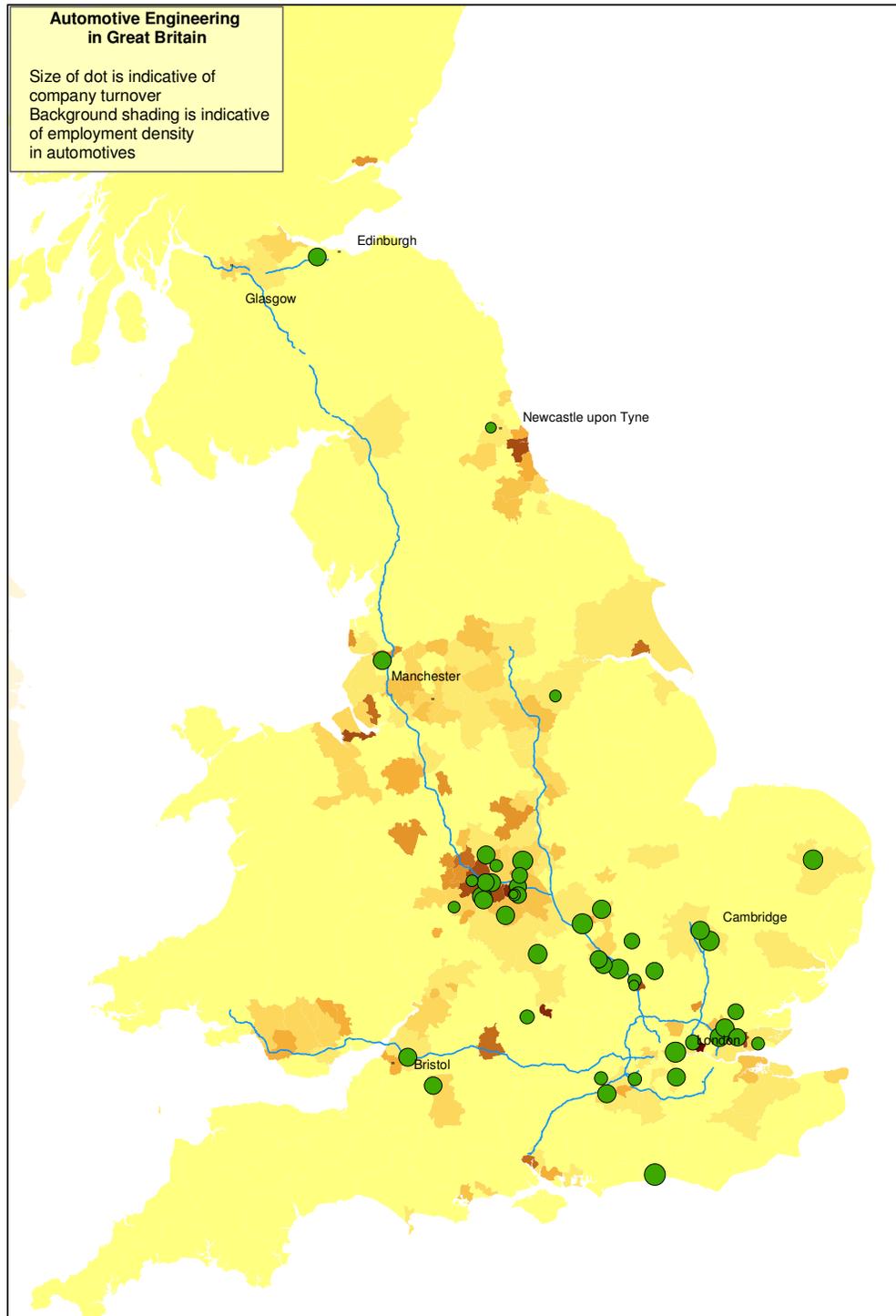
Source: ORBIS, PACEC research

Does the UK automotive design engineering sector cluster?

- 8.3.5 The automotive IDE sector in the UK forms two distinct clusters. The first cluster is centred on Birmingham and Coventry, close to the automotive OEMs and their supplier base in the Midlands. A second has formed around the Ford plants in Basildon, Essex. IDE clustering is primarily due to customer preferences, although there are also labour market advantages.
- 8.3.6 Some of the larger design companies are located outside these clusters. Ricardo is located in Shoreham, West Sussex, near the family home of its founder Sir Harry Ricardo. At the same time, it has strategically placed technical centres and sales offices near key customer bases in the Midlands (UK), Detroit (USA), Japan, China, Korea, India and Italy⁹⁵. Thus proximity to customers is important in some, but not all markets. Lotus Engineering is located outside the main UK automotive clusters in Norfolk, but has offices in Michigan, USA. Local offices let IDE companies meet customer proximity requirements without having to completely decentralise production by region.

⁹⁵ Locations obtained from Ricardo's website: www.ricardo.com

Figure 8.11 Location of UK automotive IDE firms



Source: PACEC research, ORBIS

8.4 The Indian design engineering sector⁹⁶

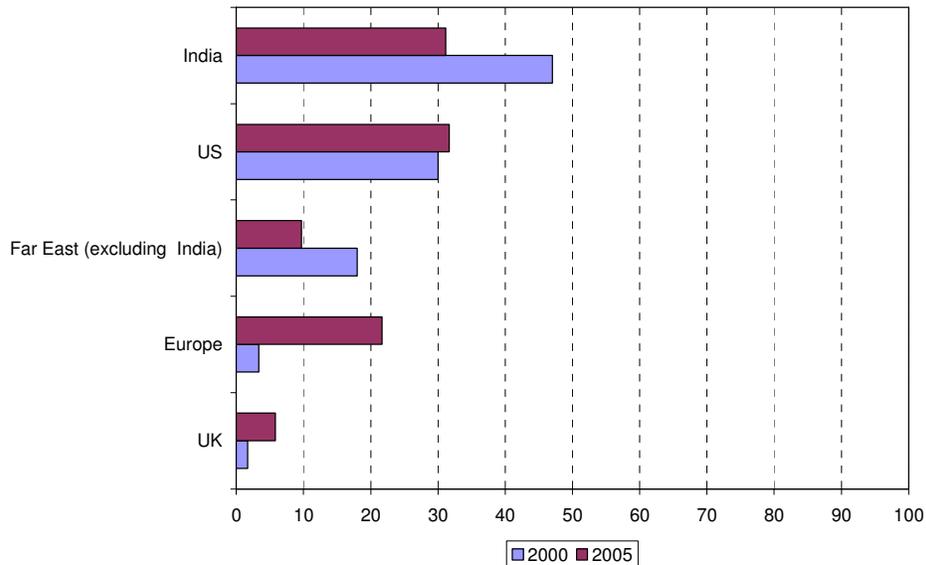
8.4.1 The emerging Indian automotive IDE sector presents both an opportunity and threat to the UK sector. UK IDE companies may be able to improve competitiveness and access to markets by collaborating with low-cost Indian partners. However, the continued improvement of design capabilities in India suggests that these could pose a competitive threat in the future.

Overview of the Indian design engineering sector

8.4.2 A survey of six Indian IDE companies for the DTI revealed a sector that was rapidly developing capabilities and attracting global customers. Domestic Indian customers and the US were their main target markets, with Europe increasingly important during the period 2000-2004 (Figure 8.12).

8.4.3 As in the UK, the main competition for design budgets comes from in-house departments, and some Indian IDE firms (Figure 8.13). At this stage of their development, Indian IDE firms see UK IDE companies more as potential customers or collaborators than competitors, but that will not always be so.

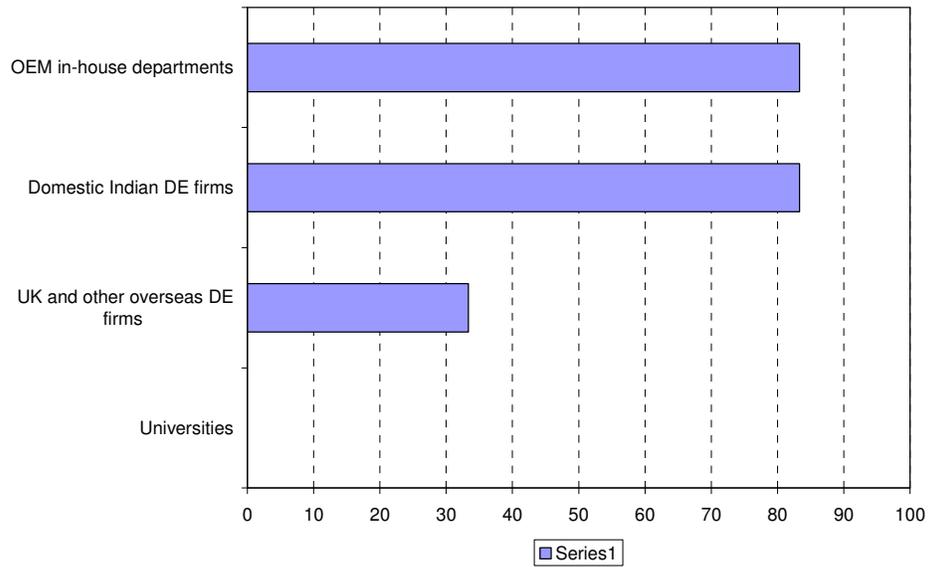
Figure 8.12 Geographic locations of the customers of Indian IDE firms



Source: Results of the 2005 Global Watch scoping mission to India on Automotive Design Engineering
Number of respondents: 6

⁹⁶ The following section draws on a study undertaken for the DTI ("Automotive Design Engineering – a scoping mission to India", Report of a DTI Global Watch Mission, 2005) scoping the automotive design engineering sector in India, and PACEC research.

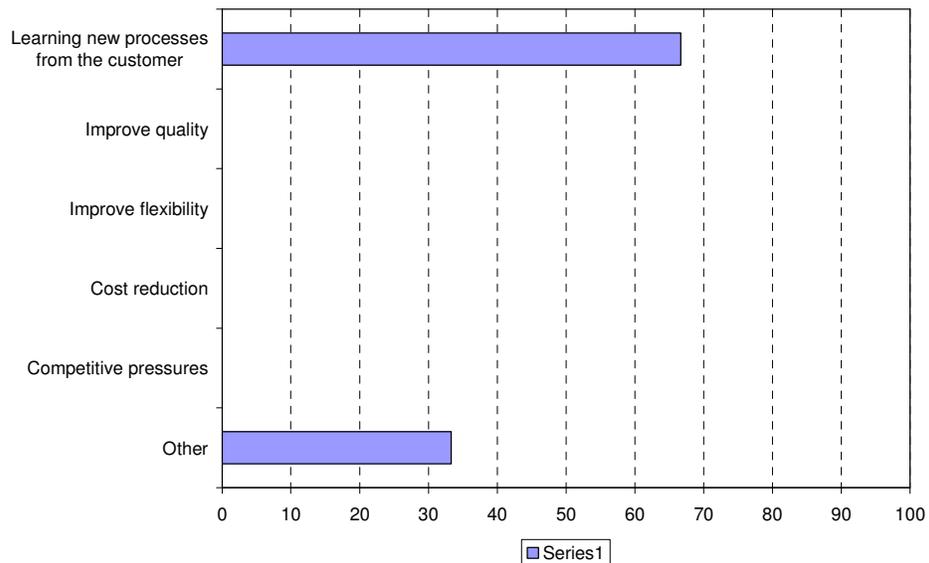
Figure 8.13 Types of competitors



Source: Results of the 2005 Global Watch scoping mission to India on Automotive Design Engineering
 Number of respondents: 6

8.4.4 Innovation was seen as important, with all the firms surveyed introducing new innovations in both products and processes, and 67% of respondents innovating in their business model. The main motivation was the need to develop capabilities by learning about customer processes, rather than to improve quality, flexibility, or reduce costs (Figure 8.14).

Figure 8.14 Drivers of innovation

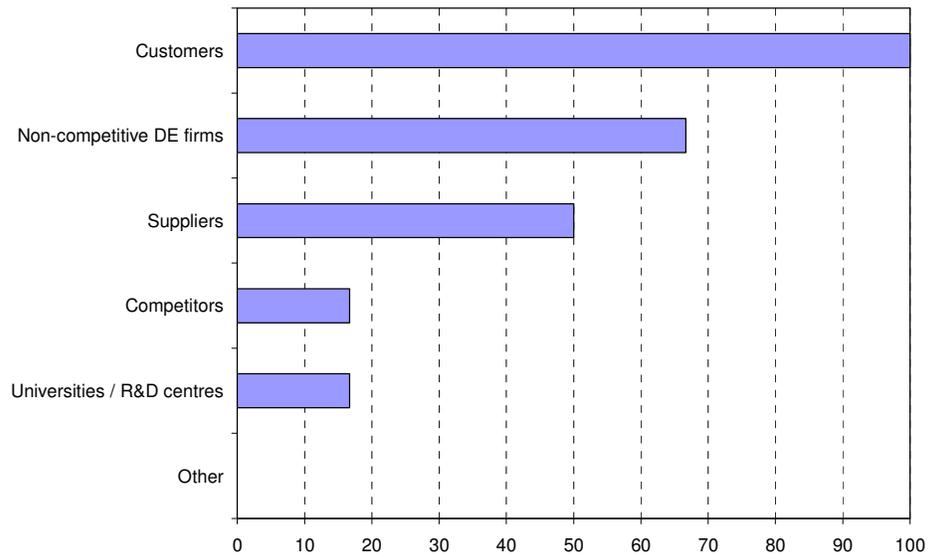


Source: Results of the 2005 Global Watch scoping mission to India on Automotive Design Engineering
 Number of respondents: 6

8.4.5 Collaboration was seen by most of the six companies as very important to competitive advantage. All of them collaborated with customers, although

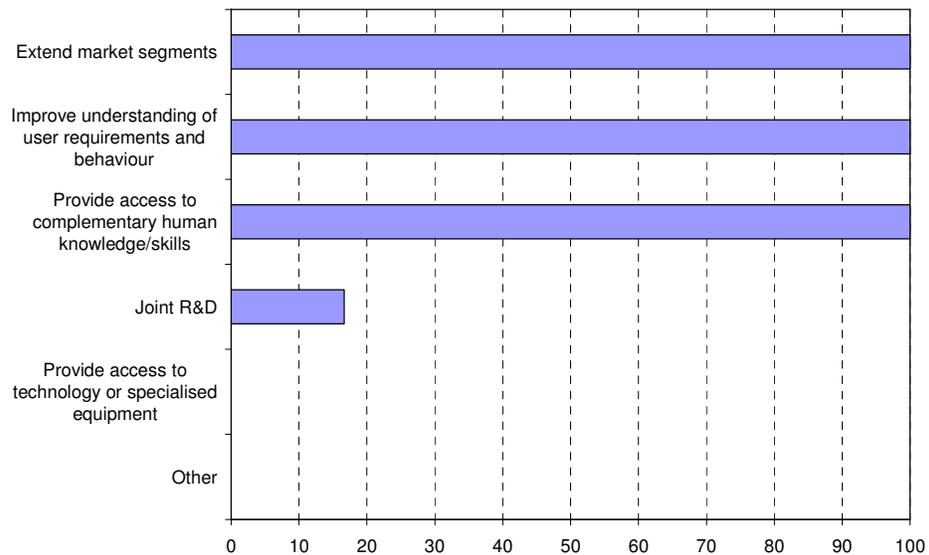
collaboration was typically informal. Indian IDE firms also collaborated extensively with non-competitive IDE firms and other suppliers to their customers (Figure 8.15). The main reason for collaboration was to gain access to complementary knowledge and skills, extend market diversification, and improve understanding of user requirements (Figure 8.16).

Figure 8.15 Collaboration with different types of firms



Source: Results of the 2005 Global Watch scoping mission to India on Automotive Design Engineering
Number of respondents: 6

Figure 8.16 Reasons for collaboration



Source: Results of the 2005 Global Watch scoping mission to India on Automotive Design Engineering
Number of respondents: 6

Developments in design engineering capabilities in India

- 8.4.6 This section first examines IDE companies that are owned by OEMs, then those owned by Tier 1s, and lastly 'autonomous' IDE companies.

OEM-owned IDE companies

- 8.4.7 These companies are typically highly opportunistic enterprises, closely integrated with the parent at an operational level. Such links are thought to provide significant competitive advantage, in terms of automotive experience and resources. Access to parental investment capital was not considered to be a problem. The companies were also able to benefit from favourable tax and import duty terms arising from the same 'software' related business designations used by the independent sector. Larger OEMs grew through both acquisition and organic development.
- 8.4.8 OEM owned IDE companies tended to have a strong engineering ethos, aided by access to skills in the parent organisation. There were nonetheless some deficiencies in even the best organisations, particularly in powertrain, chassis and electronics. Some internal innovation and method development was apparent, although at a lower level than in Western OEMs. The 'learning from the customer' business model was less prevalent than in the independent sector. Indeed, the formation of an IDE subsidiary might be a means for acquiring competence in known areas of weakness. An exception to this was in design for manufacture, where competence tended to derive from parental production.
- 8.4.9 The local strength of OEM brands was an advantage in the recruitment and retention of high quality engineering staff. Companies in this sector pride themselves on their ability to attract good quality graduate engineers and offer attractive salary packages.
- 8.4.10 Although there are advantages to OEM ownership, UK experience points to disadvantages, such as difficulties in winning customers among the parent's competitors.

The tier 1-owned IDE companies

- 8.4.11 Most of the advantages of OEM ownership apply to a lesser extent to Tier 1 ownership. There appears to be a narrower and more clustered spread of competences, whereby the product/service range was limited by parental specialisation.
- 8.4.12 On the other hand, Tier 1-owned IDEs have an advantage over OEM-owned competitors that customers are less likely to compete with the parent.

'Autonomous' Independent Design Engineering companies

- 8.4.13 This is an extremely large, diverse, and rapidly expanding group of companies, with widely varying levels of competence and business models. Their origins are also diverse, e.g. former software vendors and agencies, subsidiaries of multi-industry

conglomerates, specialists from non-auto sectors, and start-ups. Business models tend to be extremely flexible, ranging from a conventional project-based consultancy approach, to the provision of dedicated facilities for individual customers.

- 8.4.14 Lacking some of the recruitment and retention advantages of their OEM and Tier 1 counterparts, human resource strategies are extremely important. A number of innovative approaches were demonstrated, aimed at limiting and mitigating attrition, such as enhanced career development of core staff and stock options.
- 8.4.15 Despite including some highly innovative and entrepreneurial companies, the Indian IDE sector is more exposed to demand volatility. Many focus on the provision of lower value services which are under threat from improvements in IT, such as mesh generation software. Larger customers are moving away from outsourcing in favour of developing local in-house facilities. This has led many in the Indian IDE sector to predict that some form of consolidation is inevitable.

General observations on the emergence of design engineering capability in India and China

- 8.4.16 There is a skills deficit relative to Western IDE companies in powertrain, chassis and electronic systems engineering.
- 8.4.17 Stand-alone IDE companies in China focus on the domestic market. Their skills deficits and involvement in 'reverse engineering' would make it difficult for them to compete in overseas markets. In contrast, the growing Indian IDE sector is focused on exporting to Western markets.
- 8.4.18 The Indian design sector has expanded rapidly, and a number of Indian IDE companies have opened offices in the US and Europe (including the UK) since early 2006. These are typically sales operations or small engineering outposts.
- 8.4.19 At the moment, the priority for Indian and Chinese design operations is to upgrade their capabilities. Thus, they are more likely to be customers for Western IDE companies' services than competitors, but this could be reversed in less than ten years.

8.5 The productivity performance of the UK design engineering sector

8.5.1 This section provides an overview of the productivity performance of the sector, how it changed over the period 2000-2004, and how it compares to similar sectors in Europe^{97,98}. It then examines company performance, ranking it according to several measures. Finally it explores company efficiency and the factors that explain it.

Table 8.4 Productivity measures during the period 2000-2004

	2000	2001	2002	2003	2004	CAGR 2000-2004 (%)
Turnover per employee (£000s per employee)	83	88	89	94	91	2.3
	(100)	(106)	(107)	(114)	(110)	
GVA per employee (£000s per employee)	29	34	37	40	35	4.9
	(100)	(118)	(127)	(139)	(121)	
Turnover per unit labour costs (%)	254	265	264	265	251	-0.3
	(100)	(104)	(104)	(104)	(99)	

Note: Figures in brackets are indexed changes with 2000=100
Source: ORBIS, PACEC analysis

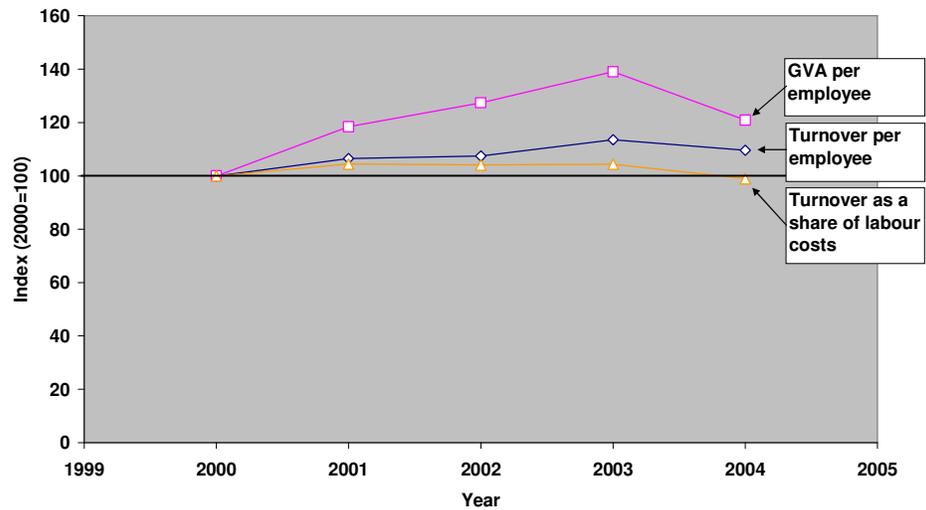
8.5.2 Gross Value Added (GVA) is Turnover minus the Cost of Goods and Services (approximately equal to wages plus profits plus amortisation, in the definition used by the Office for National Statistics).

8.5.3 In 2004, the UK auto IDE sector generated about £91,000 of turnover per employee, and £35,000 of gross value added per employee (Table 8.4). GVA per employee grew about 5% per annum over the period 2000-2004 (12% per annum over 2000-2003).

⁹⁷ The comparison does *not* include AVL and FEV, two of the foremost engineering services firms globally due to a lack of data. This should be born in mind when making comparisons with the European sector.

⁹⁸ It was not possible to compare the US and UK sectors because the majority of US automotive design engineering companies are private and consequently do not have to make their annual accounts public.

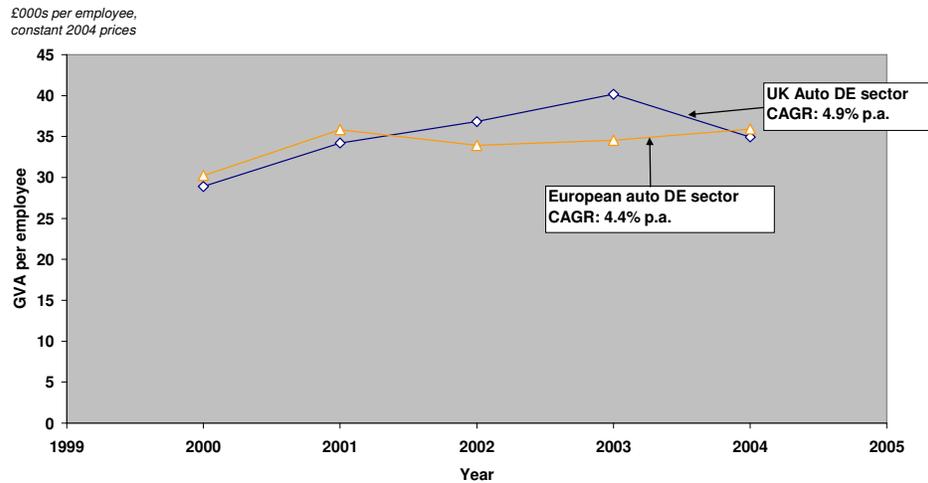
Figure 8.17 Evolution of the productivity measures over the period 2000-2004



Source: ORBIS, PACEC analysis

8.5.4 Figure 8.17 shows how sectoral productivity increased over the period 2000-2003, before declining in 2004. At a company level, IDE firms with a powertrain focus most closely tracked the sectoral trends, but others did not.

Figure 8.18 Evolution of GVA per employee during the period 2000-2004



Source: ORBIS, PACEC analysis
European analysis does *not* include AVL FEV due to a lack of data for these companies

8.5.5 Figure 8.18 compares the evolution of GVA per employee for the automotive IDE sector in the UK to that of a comparable sector in Europe. Productivity in the UK automotive IDE sector grew steadily from 2000 until 2003 but declined substantially in the latest year, 2004. It outperformed the European IDE sector during the period 2002-2003.

8.5.6 Of the measures presented in Table 8.4, gross value added per employee is considered to be the most meaningful. Turnover per employee is considered a poor measure of productivity because it is influenced by differences in outsourcing and materials intensity. Care still needs to be taken with inter-company comparisons of GVA per employee to ensure that like is compared with like, in particular with respect to capital intensity. A high GVA per employee does not necessarily imply high profitability (e.g. a firm which over-invests in capital equipment could improve labour productivity but reduce profitability), but it provides a good indication of the ability of a firm to pay wages and profits and cover the depreciation of capital.

8.5.7 It should be remembered that the sector primarily generates revenue from the sale of design capability on a contract basis. This revenue is a function of the fee rate, the number of contract days, and the utilisation rate of their staff. Evidence from the case studies suggests that firms in this sector are largely price takers, so improvements in productivity in the short run (for a given capital intensity) will be largely due to increased volumes.

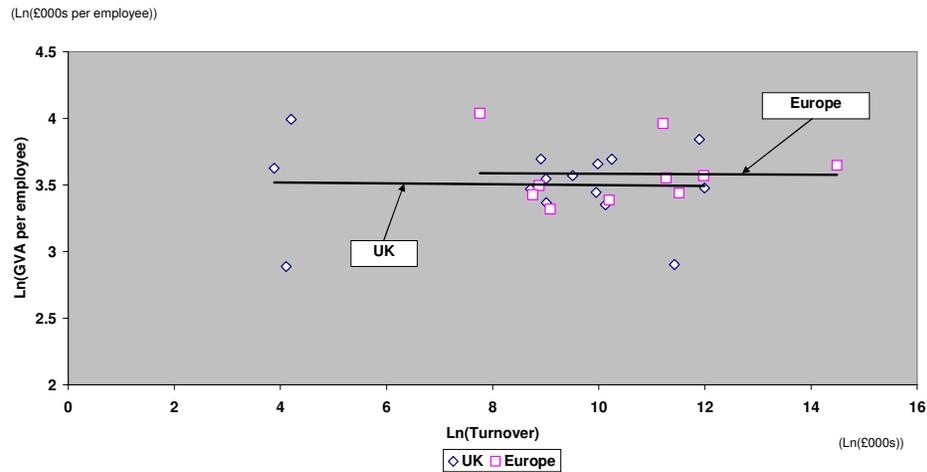
Does size matter?

8.5.8 There are a number of reasons why it could be advantageous to be a relatively large IDE company. This is an important issue for IDE firm strategy, and will be discussed in the next chapter

8.5.9 This section applies a simple test of the proposition that higher productivity is correlated with relatively larger size. Size is proxied by both employment and turnover, in order to test the robustness of the results.⁹⁹ By plotting the natural log of productivity against the natural log of size, we can easily observe the elasticity of productivity with respect to size (i.e. the effect of a change in size on the change in productivity).

⁹⁹ Both employment and turnover are commonly used to indicate size, and which is better depends on the question asked. Neither are entirely satisfactory eg a small firm in terms of employment could be a large player in the market, and a firm with large turnover could have few employees and outsource nearly everything.

Figure 8.19 Relationship between productivity (GVA per employee) and size (turnover) in 2004



Source: ORBIS, PACEC analysis

8.5.10 Figure 8.19 suggests that there are no gains to *productivity* to be made by being larger. This result is confirmed using a simple linear regression of the natural log of productivity on the natural log of size, using Ordinary Least Squares (OLS). A dummy variable has been inserted to control for the effect of location in the UK or in Europe. This yields the following regression equation:

$$8.5.11 \quad \ln(\text{Productivity}) = \alpha + \beta \ln(\text{Size}) + \delta \text{Country}$$

where *Productivity* is proxied by GVA per employee, *Size* is proxied by either turnover or number of employees, *Country* is a dummy variable (UK = 1 and Europe = 0), α is a constant and β is the elasticity¹⁰⁰ of productivity with respect to size.

Table 8.5 Regression results analysing the effect of size on productivity (GVA per employee)

		2000	2001	2002	2003	2004
Size: Turnover	β	-0.026	0.003	-0.005	0.021	-0.003
	t-ratio	-0.78	0.11	-0.16	0.62	-0.12
	R ²	0.034	0.003	0.017	0.031	0.023
Size: Employment	β	-0.045	-0.011	-0.023	0.002	-0.016
	t-ratio	-1.28	-0.40	-0.68	0.07	-0.61
	R ²	0.076	0.010	0.036	0.014	0.038

Notes:

(1): The coefficient on the dummy variable was always insignificant at the 1%, 5% and 10% levels of significance and is not presented in the above table.

(2): Number of observations: 25

Source: PACEC analysis, ORBIS

8.5.12 The simple regression analysis cannot reject the null hypothesis that the elasticity of productivity with respect to size is insignificantly different from zero even at the 10% level of significance.

¹⁰⁰ The proportionate increase in productivity from a unit increase in size.

- 8.5.13 This confirms the evidence presented in Figure 8.19 that companies in the automotive IDE sector do not benefit from economies of scale in any obvious way. This is not conclusive however, because size may affect productivity performance in more indirect ways. For example, the interviews and discussions with industry experts suggest that size has important implications for a company's ability to compete, acquire knowledge, cover the fixed costs of entry into markets, and develop a reputation. Another explanation for this result is that these companies are operating in different niches. To compete directly with larger companies would require similar scale, capabilities and experience. However, there are enough niches in design engineering to allow considerably smaller companies to have reasonable productivity performance.

8.6 The efficiency of design engineering companies

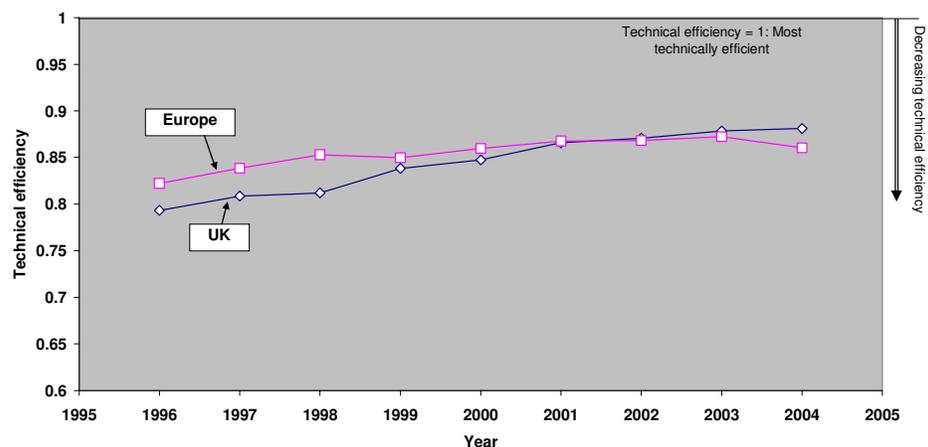
8.6.1 This section presents the evolution of technical efficiency both at the sector and company level. Technical efficiency measures a firm's ability to combine inputs to create output, using a given technology relative to the maximum that can be generated by that technology.

Evolution of the efficiency of the UK automotive design engineering sector

8.6.2 The technical efficiency for the automotive IDE sector were estimated using Stochastic Frontier Analysis (SFA) over the period 1996-2004, utilising an unbalanced data panel. As for the electronics IDE sector, the econometric model is based on Battese and Coelli (1993). Similarly, the lack of firm-level input price data meant that it was not possible to fully specify the cost function thus rendering the cost efficiency measure much less reliable than the technical efficiency. For this reason, the cost efficiency analysis has been excluded from the main body of the report, with the focus primarily on technical efficiency instead. The cost efficiency results can be found in Appendix C.

8.6.3 Figure 8.20 shows that technical inefficiency of the UK IDE sector improved over the period 1996-2004, and more rapidly than in the comparable European sector. Therefore, on average, companies in the UK sector moved more rapidly towards the technology production frontier than their European counterparts, which they overtook in 2001.

Figure 8.20 Evolution of the technical efficiency of the UK and European IDE sector over the period 1996-2004. Maximum technical efficiency = 1.



Source: PACEC analysis, ORBIS

How efficient are UK companies?

- 8.6.4 The combination of the SFA estimation method, with access to the firm-level accounting data, allows for the analysis of firm-level efficiency
- 8.6.5 The study found that technical inefficiency tends to lie within a band of 0.80 and 0.90 for both groups. Chapter 5 (analysing the electronics IDE sector) found that young companies typically had a low technical efficiency, but that this increased rapidly, moving into a range of 0.80 to 0.90 as companies matured and survived. The auto IDE sector does not currently attract young new entrants and so the story is rather one of mature companies consistently making gradual improvements in their utilisation of resources.
- 8.6.6 The companies were ranked according to various measures of performance (productivity, profitability and technical efficiency), and the correlations between the rankings calculated (see Table 8.6). The following results emerge:
 - There is little correlation between size and productivity and profitability (confirming the results found earlier of no benefits from economies of scale for productivity)
 - There is a strong positive correlation between productivity and profitability, suggesting that as firms become more productive, they are able to capture a greater share of the profits
 - The correlation between financial performance measures (gross value added per employee and profits as a share of turnover) and technical efficiency is not particularly strong

Table 8.6 Rank correlations for different measures of size and performance (size, productivity (GVA per employee), profitability (profits as a share of turnover), technical efficiency and cost efficiency).

	Turnover ranking	Average productivity ranking	Average profitability ranking	Average technical efficiency ranking
Turnover ranking	1.00	0.18	0.07	-0.39
Average productivity ranking	0.18	1.00	0.71	-0.51
Average profitability ranking	0.07	0.71	1.00	-0.46
Average technical efficiency ranking	-0.39	-0.51	-0.46	1.00

Source: PACEC analysis, ORBIS
 Average: mean ranking over the period 2000-2004
 Productivity: Gross value added per employee
 Profitability: Profits as a share of turnover
 All measures deflated and in constant 2004 prices where appropriate

Determinants of Inefficiency

- 8.6.7 Following the methodology outlined in Chapter 5 for the efficiency analysis for the electronics design engineering sector, the production function was estimated and the systematic part of the error term was separated from the random component. This measure of technical inefficiency was then regressed on potential (primarily spatial) determinants. The results are presented in Table 8.7. The estimation of the

production function is presented in the top part of the table and that of the determinants of technical inefficiency in the bottom part.

- 8.6.8 A number of different functional form specifications were estimated (Cobb-Douglas, trans-log and flexible-Fourier). As with the analysis of the electronics IDE sector, the Cobb-Douglas specification provided the best fit to the data.
- 8.6.9 The results of the production function estimation suggest the following:
- The scale of production (the anti-log of the value of the constant) is 21.3, which is similar to that in the electronics IDE sector (for the cross-country analysis). This suggests similar levels of technology between the automotive IDE and electronics IDE sectors.
 - The elasticities of output with respect to capital and labour are 0.42 and 0.59 respectively.
 - The sector appears to exhibit constant returns to scale (summing the coefficients, the elasticities of output with respect to capital and labour is 1.01). This is unsurprising since, as with the electronics contract design house sub-sector, they act primarily on a consultancy-project basis; doubling the inputs of capital and labour should double output.
- 8.6.10 Turning to the determinants of technical efficiency, the following key results were obtained (recalling that a negative coefficient implies improvement in technical efficiency as it moves the company toward the frontier):
- Size does not impact on the technical efficiency of a company;
 - The number of patents in the geographical area where companies are established positively impacts on the level of inefficiency. This somewhat perverse result suggests that factors other than a location's innovative 'performance' determine a company's efficiency. Examples could include ease of access to customers and the ability to access innovation and knowledge globally rather than locally, both of which could not be proxied in our model given the data constraints.
 - Having non-UK offices appears to benefit technical efficiency. This could be due to being closer to customers, resulting in fewer efficiency losses during the collaborative relationship (see Chapter 9 for more discussion on collaboration); or being closer to markets resulting in an improved ability to allocate resources efficiently.
 - The econometric results suggest that younger companies have an efficiency advantage over older companies (the coefficients on both age dummies are negative and statistically significant). However, the case study evidence contradicted this finding, which suggest that automotive DE companies can realise significant benefits from the learning-by-doing process, accumulated knowledge (much of which may be very difficult to codify), and accumulated capabilities which can only be gained through many years of experience within the field.
 - Proximity to universities does not appear to have any effect on technical efficiency. A glance at the successful companies and their locations shows that their main offices are not necessarily centred around the customers (although they will typically have satellite offices near the customers). This suggests that their reputation may be such that they can easily attract the necessary labour and access the knowledge base, and would experience no extra efficiency benefits from being located near a university.

8.6.11 One should be cautious when interpreting the econometric results. The results for technical inefficiency are likely to have limitations, and should be qualified accordingly. Although the estimates for the coefficients in the production function are statistically significant and have expected signs and magnitude, the estimates for the determinants of inefficiency effects are either non significant (statistically non significant), or have very small magnitudes.

Table 8.7 Results of the technical efficiency analysis

Production function		
Variable	Coefficient	t-ratio
Constant	3.06	64.92 ***
Current assets	0.42	10.59 ***
Employment	0.59	11.89 ***
Determinants of Inefficiency		
Variable	Coefficient	t-ratio
Constant	1.37	2.56 ***
Employment	-0.002	-0.24
Total employment	-0.00002	-2.20 **
University Impact	0.0002	1.32
Patents	0.02	2.21 **
Non-UK offices	-0.30	-3.71 ***
Age dummy <10	-0.41	-3.65 ***
Age dummy 11 < 25	-0.28	-2.42 ***

Note: ***: 1% significance; **: 5% significance; *: 10% significance

Note: All the variables described in chapter 5 were included in the regressions and many different specifications were estimated. Only the most relevant one is presented here.

Source: PACEC analysis

9 How automotive design engineering companies compete

9.1 Introduction

9.1.1 The automotive IDE sector, both in the UK and globally, has been faced with difficult strategic decisions over the past decade. The key question has been how to respond to declining and changing demand from traditional customers. Different strategic positions have emerged which seek to match their capabilities and characteristics to perceived opportunities.

9.1.2 The strategic options available to these firms depend on their size and their maturity. Younger and smaller firms are less able to offer a full-service capability than large established and integrated IDE service firms. The analysis, therefore, considers the strategic options for small specialised IDE firms and large integrated IDE firms separately. The findings suggest that even within these separate groups, there has been no convergence to a single dominant strategy.

9.1.3 The chapter first explores the barriers to entry and competitive advantages in the various markets. It then analyses how companies compete to secure competitive advantage. The analysis is based on a postal survey of firms and interviews with senior executives in the design engineering and automotive industries.

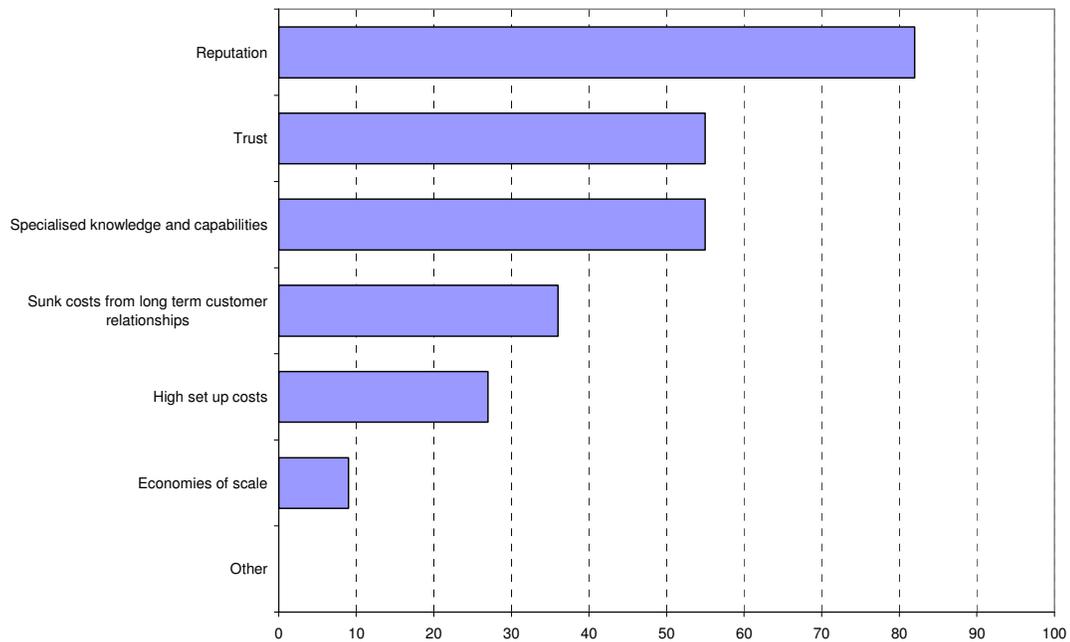
9.2 Barriers to entering the market

9.2.1 This section discusses the main barriers to entering the market for outsourced design engineering as perceived by incumbents. The barriers vary by market niche, e.g. powertrain work requires significant initial capital investment as well as specific expertise and knowledge, while body-in-white¹⁰¹ operations face lower set-up costs and reputation premiums.

9.2.2 The survey of firms revealed that reputation is the key barrier, with 82% of respondents believing this to be very significant or crucial (Figure 9.1). The associated factors of trust, and specialised knowledge and capabilities are the next most important, and were cited by 55% of respondents.

9.2.3 Economies of scale are not seen as a barrier to entry, supporting the findings from the data analysis in Chapter 8.

Figure 9.1 Barriers to entering the market



Source: PACEC Survey
Number of respondents: 11

¹⁰¹ Body-in-white refers to the phase in which the final contours of the car body are worked out, in preparation for ordering of the expensive production stamping die.

Reputation and trust

- 9.2.4 The customer base of automotive IDE firms is very concentrated. Extensive consolidation has occurred over the last decade and is expected to continue. The number of major OEMs (in the three major automotive markets) has shrunk from 52 in the 1960s to approximately 12 today. The number of Tier 1 suppliers also shrunk from 2,000 in 1990 to just 600 in 2000¹⁰², partly driven by OEM preferences for 'qualifying supplier' networks and the outsourcing of larger modules of work to the supplier base (see Chapter 6).
- 9.2.5 If they are to break into qualifying supplier networks, new entrants must demonstrate an ability to complete projects to specification, to a sufficient quality standard, and on time. An unblemished track record is, therefore, very important, particularly where there is considerable risk to the customer in outsourcing. However, customers' cost reduction programmes and the shift of the outsourcing decision from engineering departments to procurement have increased the importance of price competitiveness relative to quality and reputation. This is highly dependent on the prevailing strategic views of the management teams and budget constraints, and could reverse in the future.
- 9.2.6 Potential entrants are confronted by incumbents who have developed personal relationships with customers, based on trust, with the strength of these relationships increasing with every successfully completed project. New entrants have to find a way to win trust, or compensate for the additional risk the customer faces.
- 9.2.7 The emerging automotive markets, such as China and India, are providing a new opportunity for IDE firms. Unlike the consolidations occurring in the major automotive regions, these countries are witnessing growth in the number of OEMs, many of whom want to upgrade their capabilities. The barrier to entry with regards to reputation and trust will likely be lower here.

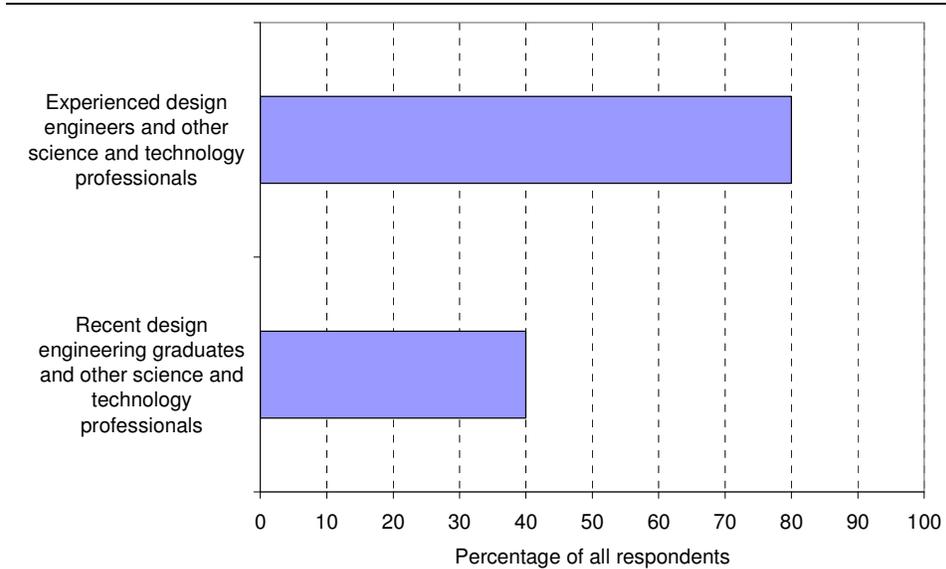
Accumulated knowledge

- 9.2.8 As companies mature and consolidate their track record, they accumulate tacit knowledge which is not easily replicated. Tacit knowledge is defined here as that which is not easily codified. It is stored in employee's heads, not in books or online. The importance of accumulated knowledge as a barrier depends on the market niche. The complexity of powertrain design engineering means that problem-solving is highly reliant on accumulated experience and tacit knowledge, while in 'body-in-white' and some of the more routine simulation work, the ability to codify and, hence, replicate knowledge is much greater, and so barriers are much lower.
- 9.2.9 One solution to overcoming this barrier is to recruit experienced professionals with the appropriate knowledge in order to build up a capability over time. This is not easy because tacit knowledge is often a team attribute, and people are likely to be more

¹⁰² Accenture (2006) "High Performance in the Automotive Supplier Industry", presentation obtained from www.accenture.com

productive in their current post than with the company trying to replicate the capability. Nonetheless a considerably higher wage has to be offered to attract them. At the moment, experienced professionals are in short supply across the sector, hindering, rather than helping entrants.

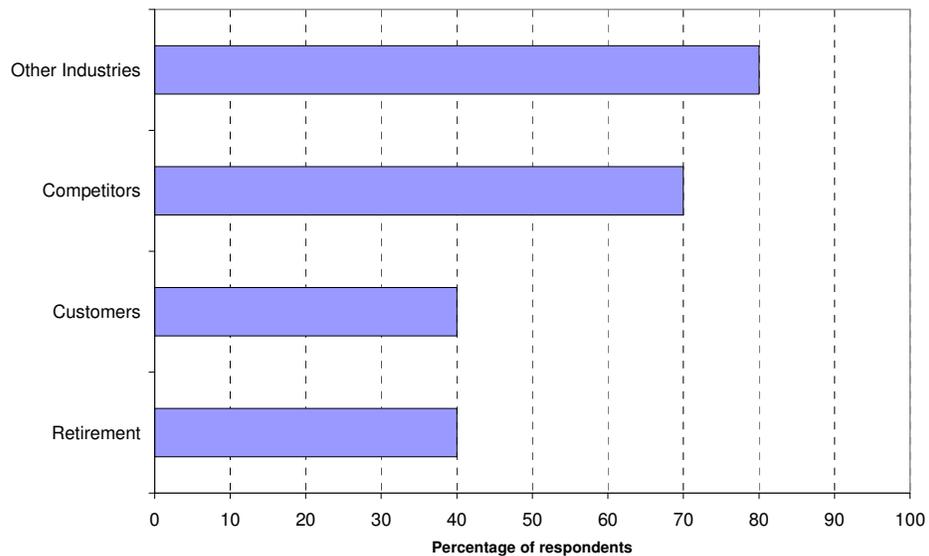
Figure 9.2 Difficulty in recruiting skilled labour



Source: PACEC survey
Number of respondents: 11
Percentage of respondents citing the difficulty to recruit as moderately difficult or very difficult
Question: How difficult are you finding it to recruit... (enter a score from 1-4 indicating the level of difficulty)

9.2.10 Related to the difficulty in recruiting experienced engineers, the IDE firms surveyed suggested that when engineers leave their companies, it is not primarily to retirement or 'poaching' by customers, but to move to other industries (Figure 9.3). This is worrying for the UK IDE sector as it diminishes the available supply of labour from which to draw upon. Movement of labour between competitors also appears to be common amongst IDE firms.

Figure 9.3 Loss of design engineers



Percentage of respondents ranking each category from 1-4 in order of importance

Source: PACEC survey

Question: If design engineers and other science and technology professionals leave your company is it to...

Number of respondents: 11

Access to finance

- 9.2.11 Companies in some design activities such a powertrain and testing, incur significant fixed capital investments. However some of these fixed costs (e.g. software and computers) are falling rapidly.
- 9.2.12 It was also noted in Chapter 8 that some providers were being asked to accept contracts with a significant royalty component (payment if and when the product is successful). If the shifting of risk to providers becomes more common, companies in the sector would need bigger financial reserves, which might encourage suppliers to become larger or seek much larger partners/owners.
- 9.2.13 Accessing finance is, therefore, be very important, especially for the small specialised providers who have promising technologies and need to fund their initial development programmes to prove their capability to OEMs. Many sources of finance are available, including venture capital, angel funding, regional (e.g. Advantage West Midlands) and central government grants, and European Union framework funding. Understanding how to benefit from different funding mechanisms can take time, thereby increasing entry costs.

Qualifying supplier networks

- 9.2.14 There are substantial costs to joining a qualifying supplier network, such as the costs of acquiring quality standards certification and integrating with the customer's way of working. This cost effectively prohibits many small companies from accessing the

network. Although the rise of networks has, in principle raised barriers to entry, the increased importance of cost in the outsourcing decision has reduced them. However, because of the significant importance to the OEMs of a minimum level of quality, overcoming this barrier to entry is crucial; and achieving lowest cost, given this minimum quality standard, becomes an important competitive advantage.

Summing up: the barriers to entry

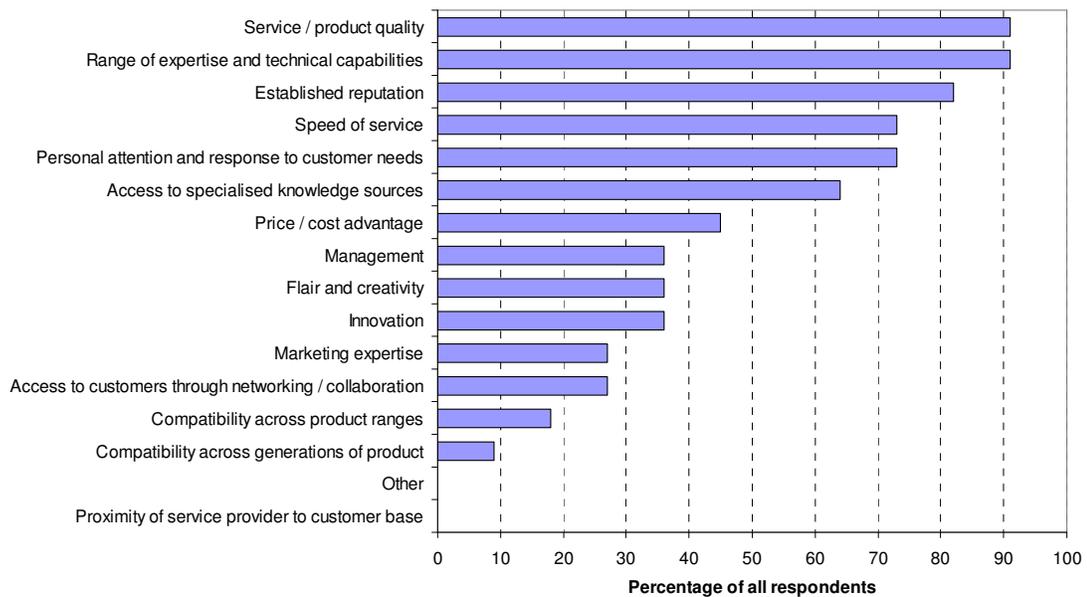
- 9.2.15 The barriers faced by potential entrants depend on the market niche. In some markets, barriers are low, but in others the capabilities, reputation and customer relationships of incumbents would be difficult to replicate. Some of these barriers are being eroded by OEM cost-reduction pressure, which has implications for how companies secure competitive advantage after entry.

9.3 Competitive advantages in the UK sector

9.3.1 Competitive advantage can be in price or non-price factors. Price factors include the direct as well as indirect transactions costs of engaging a provider.

9.3.2 The key non-price factors from which the UK automotive IDE sector derives its core competitive advantages are the quality and scope of innovations, creativity¹⁰³ and flexibility (Figure 9.4). The main price factors are speed to market, reliability and customer responsiveness¹⁰⁴.

Figure 9.4 Competitive advantages of the UK IDE sector



Percentage of respondents ranking factor as very significant or crucial
 Source: PACEC survey
 Number of respondents: 11

9.3.3 The interviews for this research found that the UK automotive IDE sector had specific geographic and branding disadvantages, relative to comparable sectors in Europe and the US.

Non-price competitive advantages

Quality and scope of capabilities

9.3.4 The most important competitive advantages in the IDE sector are in the quality and scope of technical and innovative capabilities. This is unsurprising because the

¹⁰³ Flair and creativity was only cited by 36% of firms in the survey as being a very significant or crucial competitive advantage. However, most of the case study interviews claimed this was one of the core competitive advantages of the UK design engineering sector.

¹⁰⁴ Based on interviews with senior executives in the automotive design engineering and OEM sectors, and the survey of firms.

sector is, by definition, involved with finding IDE solutions to customers' problems, whether for capability or capacity reasons. Many of those interviewed claimed that one of the main strengths of the UK sector was the creativity of its engineers and their willingness to approach problems from a new direction. They suggested that this gave UK firms an advantage over foreign competitors in tackling some of the complex problems facing their customers.

- 9.3.5 The importance of innovation in the sector was explored in the survey of firms. Innovation is driven primarily by competitive pressures, demanding customers, improved flexibility and increasing specialisation, with more than 50% of respondents citing these factors as important drivers (see Figure 9.5). The firms surveyed pointed out a number of key benefits from innovating (see Figure 9.6):

Overall effects

- Improved profit margins
- Improved quality
- Extended product range

Impact on market share

- Increased share in existing domestic market
- Ability to enter new geographic markets

Interaction with outside partners

- Improved interactions with customers
- Improved interactions with other collaborators

Ability to respond to changes in the regulatory environment

- Improved ability to meet industry standards

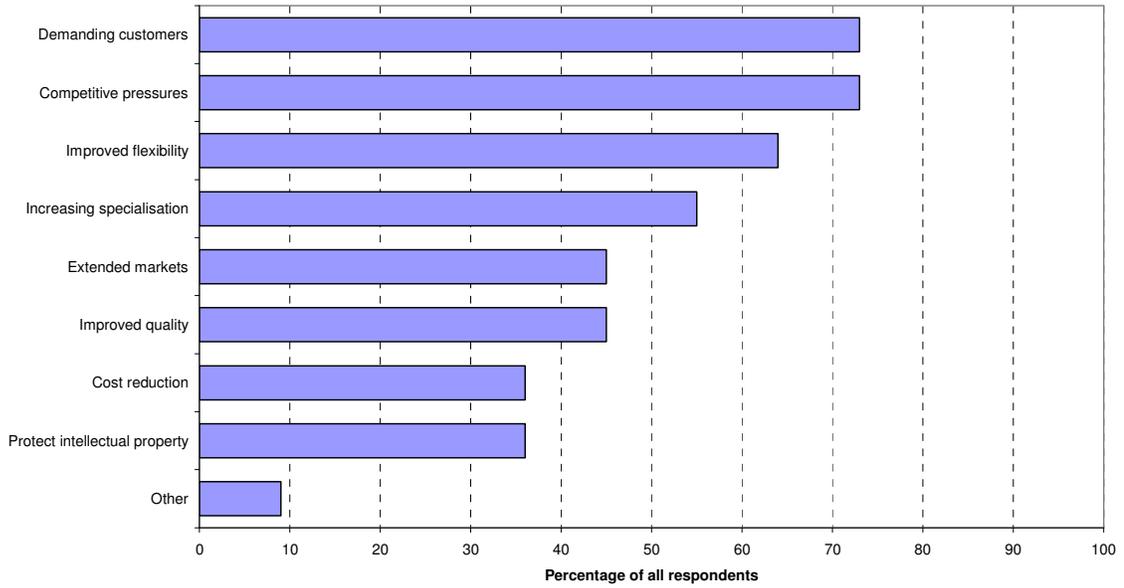
- 9.3.6 The quality of the product is almost a given in a sector dominated by qualifying supplier networks and a very concentrated customer base; a minimum level of quality is a precondition for entry. One IDE company noted that:

*“Service and product quality is a given. You have to be able to demonstrate that you can meet all the product quality standards”.*¹⁰⁵

The ability to use innovation to create the competitive advantage, focusing on the quality and scope of innovations, will be discussed at length in the next section.

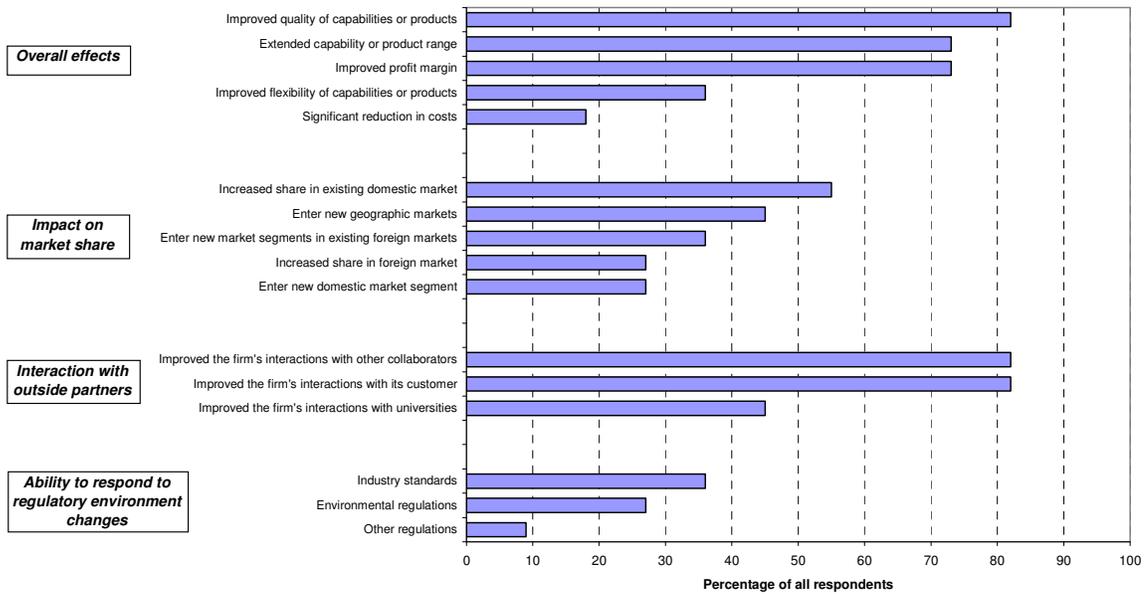
¹⁰⁵ Interview with a leading design engineering company

Figure 9.5 Drivers of innovation in the IDE sector



Source: PACEC survey
 Question: What are the main drivers of innovation for your business as a whole? (Please tick as many as apply)
 Number of respondents: 11

Figure 9.6 Impact of innovation on various aspects of the firm



Source PACEC survey
 Question: Please indicate whether the innovations mentioned in Q26 have had any effect on the following? (Please tick as many as appropriate)
 Number of respondents: 11

Reputation, track record and reliability

9.3.7 Reputation is similarly seen as a crucial competitive advantage by IDE firms, particularly in niches such as powertrain.

*“Established reputation is very important... There are only a very limited number of customers. This is not a very big industry even globally. If you do a bad job, upset a customer and take him for a ride, it will go around like wildfire”.*¹⁰⁶

*“In any different customer... [the paramount competitive advantage] is an unblemished track record in the experience of the buyer... if you have a blemished track record, you won't get [the project]”.*¹⁰⁷

- 9.3.8 Given that the global customer base is highly concentrated, the track record of delivering reliable, high quality solutions to customers' problems on-schedule and on-budget becomes a crucial competitive advantage. It provides the customer with evidence that can be used to minimise the risks associated with outsourcing.

Flexibility and speed of service

- 9.3.9 IDE companies are much smaller than their automotive OEMs customers. They are recognised as being much more nimble and flexible than their customers, reacting more quickly to emerging new technologies and changes in the labour market, and 'gearing up' more quickly for projects. Nimbleness is so vital to customers that although it is a 'given' in the design sector there is competitive advantage in being even more so.

- 9.3.10 Time-to-market is a key driver for both automotive OEMs and their supplier network. IDE companies can derive competitive advantage by offering improved speed to market. Many of those interviewed described speed to market as essential, if not the key driver of competitive advantage.

- 9.3.11 Because the customer base is limited and often face budget constraints, IDE companies must offer contractual flexibility. A key factor in being able to deliver this is the development of personal relationships with customers, to better understand requirements and constraints.

Price competition

- 9.3.12 The power to set the price for a particular project rests firmly with the customer. Again, price competitiveness tends to be a condition for entry rather than a competitive advantage. OEM pricing pressure means that a price undercutting entry strategy may not succeed due to quality concerns, although there are cases where established companies vying to enter new technological niches will use strategic pricing to facilitate entry, accept losses on particular projects in the hope of future profits. However, competitive advantage is typically based on the ability to reduce costs, e.g. via process innovation and access to lower cost regions.

¹⁰⁶ A leading design engineering company

¹⁰⁷ A leading powertrain provider

9.4 Strategies in the design engineering sector

“We want to be the premium automotive sector consultancy supplier. ... We want to be global and to be considered the best. ... We want to have all the skills ... and be able to provide a one-stop-shop for everything [the OEM] might need on the vehicle.”

– Top-tier IDE company A

“We will concentrate on our three core activities. ... While we can do other activities, we only actively sell our three core capabilities. ... This vastly improves the success rate of our bidding process”

– Top-tier IDE company B

“We used to be a ‘jack-of-all-trades’. Now we focus on areas where we have a leading edge. ... Most people aren’t interested in a one-stop-shop. They just want their project done”

– Top-tier IDE company C

9.4.1 The previous section described the competitive advantages which are important in the UK IDE sector, centred on reputation, innovation, speed of service and flexibility. The research revealed a heterogeneous set of firms, with different business models for competing. Some have moved from project-based work to providing contract labour, some are increasing the scope of their capabilities, some are focusing their capabilities on particular functional areas of the car, while others are diversifying away from auto into other sectors.

9.4.2 The above quotes highlight differences in service strategies even among the larger companies. Those offering a complete solution coexist with others offering specialised services. The comprehensiveness of service splits into:

- Integrated IDE firms that provide a range of services across entire (possibly multiple) modules or systems¹⁰⁸
- Specialist IDE firms that provide particular services across a sub-assembly or sub-system

9.4.3 Companies can be sustainable and profitable in each of these categories, which demonstrates that there is no dominant strategy. The companies also reveal different *perceptions* of the optimal strategic position. The findings of this study support the view of the sector proposed in Bouvard et al. (2002), that two key strategic positions are emerging; the full-vehicle integrator and the module specialist¹⁰⁹. Figure 9.7 illustrates the changes in strategic aspirations of companies in terms of the scope of activities offered¹¹⁰. Most shifts are between part and full-project capabilities, with an

¹⁰⁸ A module is defined as a collection of components that are assembled and supplied as a single unit, whereas a system is defined as a set of components interfaces or software that performs a key function in a vehicle (Lung, 2002).

¹⁰⁹ This section will adopt the terminology of Bouvard et al. (2002).

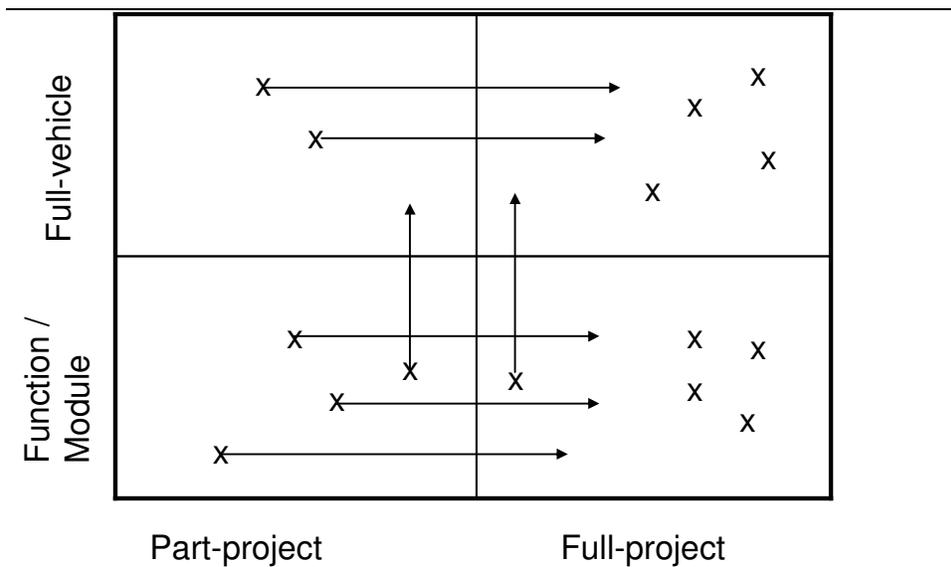
¹¹⁰ Based on the firm survey (see Figure 8.4, Chapter 8) and the interview programme.

equal split between companies that want to become complete solution providers and those that want to provide full project, specialist solutions.

- Full vehicle integrators: offer the complete range of design engineering capabilities for the full-vehicle (multiple modules and systems), as well as full project management capabilities;
- Function/Module specialists: offer the complete range of design capabilities for complete sub-assembly modules, as well as full project management capabilities.

9.4.4 No company surveyed or interviewed believed that it was desirable to remain a specialist part-of-project provider.

Figure 9.7 Aspirations of IDE companies with regards the scope of activities offered



Sources: PACEC Survey, interviews and background research, Bouvard, F., Luciat-Labry, J. and Laffont, E. (2002) "The prospects are growing for Europe's car engineering services", *McKinsey and Company Automotive & Assembly Research Unit*

Notes:

X: indicates current strategic position of a company based on the scope of its activities

Arrows indicate desired shift of company in terms of the scope of activities offered:

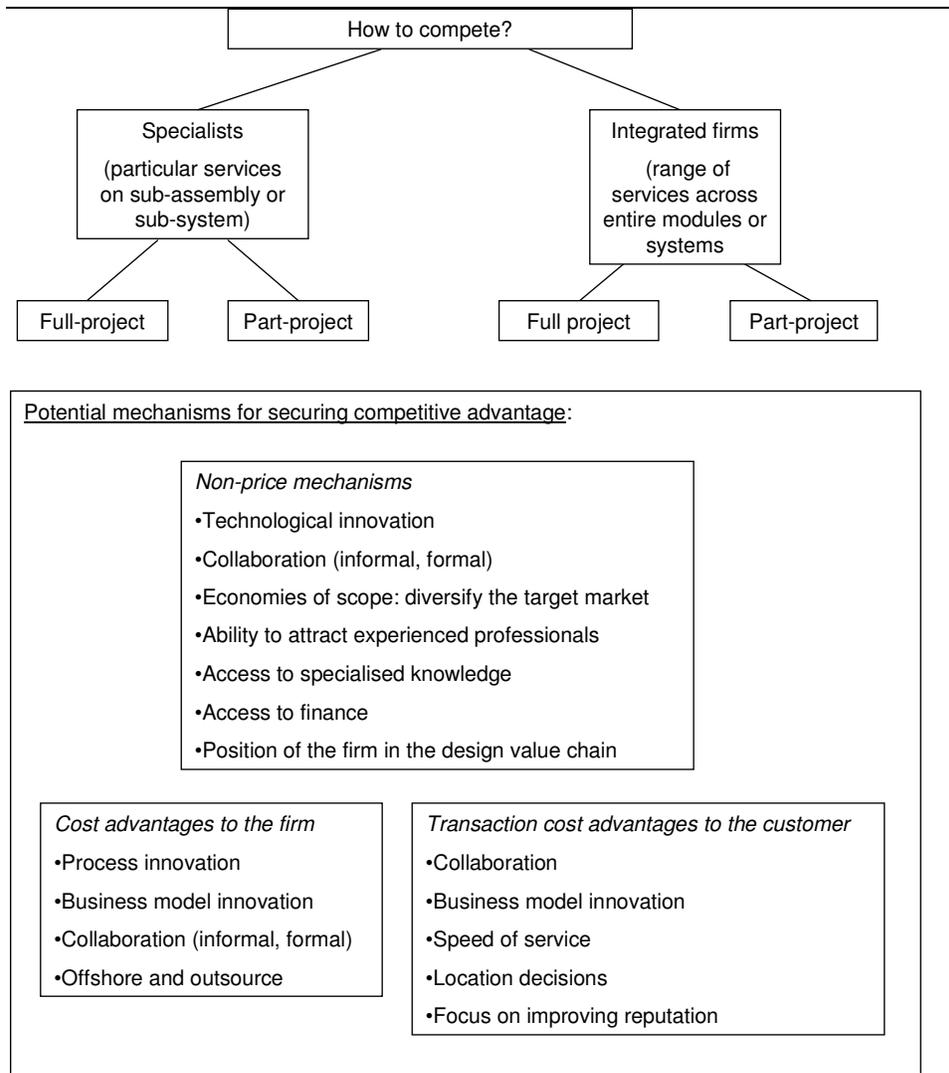
9.4.5 This section analyses issues surrounding whether a dominant strategy exists, by drawing on the experiences of different companies. It investigates:

- The importance of innovation and collaboration
 - Potential to build barriers to entry based on trust and networks
 - Greater 'enforced' collaboration between buyer and seller of design engineering capabilities
- Location decisions: the need and ability to offshore and outsource
 - Preference for local supply in auto manufacturing abroad – e.g. German IDE industry growing quite rapidly because of growth in German auto OEM base. But, German OEMs prefer domestic outsourcing, and must, therefore, be located in Germany.
- Asymmetric buyer-seller bargaining power
 - Position in the design chain, commitment
 - Effects of ownership by Tier 1 suppliers

- Provision of contract labour
- Strategic implications
 - Winner takes all: only room for a small number of full project, full-vehicle firms, but rewards substantial
 - Large companies more cost-efficient
 - Potential for customer lock-in
 - Others diversify into other sections in search of higher margins

9.4.6 The answers to the questions above will focus on the variety of mechanisms that firms may have at their disposal for developing and sustaining competitive advantage. These mechanisms are outlined in Figure 9.8.

Figure 9.8 Strategic options available to small and large players



Source: PACEC analysis

Technological innovation

9.4.7 Innovation along different dimensions, such as technological, process, business model and managerial, is seen by many companies as crucial to their competitiveness. Its importance depends on the strategic position of the company.

Disruptive technologies and modularisation

9.4.8 Companies heavily involved in activities that are prone to disruptive technological shifts, such as powertrain, view technological innovation as highly important. Engine innovation is largely incremental and development is typically kept in-house. However, major disruptions to the technology do occur, such as the emergence of hybridisation and alternative fuel technology. Depending on who pioneers the technology (e.g. OEM, university, research organisation etc.), the rate of uptake is influenced by whether the OEM considers it to be core to their future engineering

strategy, and the amount of investment required to host and develop the technology in-house. The differential rate of adoption of technology between OEMs means that some will be slower to market with the new technology and may, as a result, cede market share to their competitors.

- 9.4.9 The IDE companies that focus on disruptive technologies can do very well out of helping OEMs accelerate their rate of technology uptake. Such companies view technological innovation as crucial to their competitive advantage.
- 9.4.10 At the same time, all design companies are very commercially focussed. Many do little advanced development research themselves, but take part in collaborative programmes with universities and act as an important conduit to deliver useful technologies to the OEMs. The commercial justification is the consolidation of reputation as the provider of choice for a given technology, since applications rarely follow immediately. The largest IDE firms may finance research themselves in areas which are expected to produce a commercial return within a few years. However, 'selling' new concept products to OEMs is becoming increasingly difficult. Projects which are less certain, or have a longer gestation period, may also take place with European funding, or at a low level.
- 9.4.11 New technologies are likely to be the least modularised, so companies have to provide full-project capability. For example, innovations in electronic engine management systems have brought about performance benefits at the cost of vast increases in system complexity. The interface between engine components has become crucial, but increased complexity has made it more efficient for a single team to carry out the complete design of the system. It is therefore unsurprising that companies in this market niche are striving towards offering a complete powertrain solution.
- 9.4.12 At the other extreme, IDE companies whose business is labour-leasing (supplying engineers to work on-site with OEM in-house teams) view technological innovation as much less important for competitive advantage. Such companies are typically SMEs (small and medium-sized enterprises) who cannot afford to devote many resources to technological innovation.

Process innovation

"We must continually innovate [in processes] to do things better faster and cheaper... [in order] just to stay competitive"

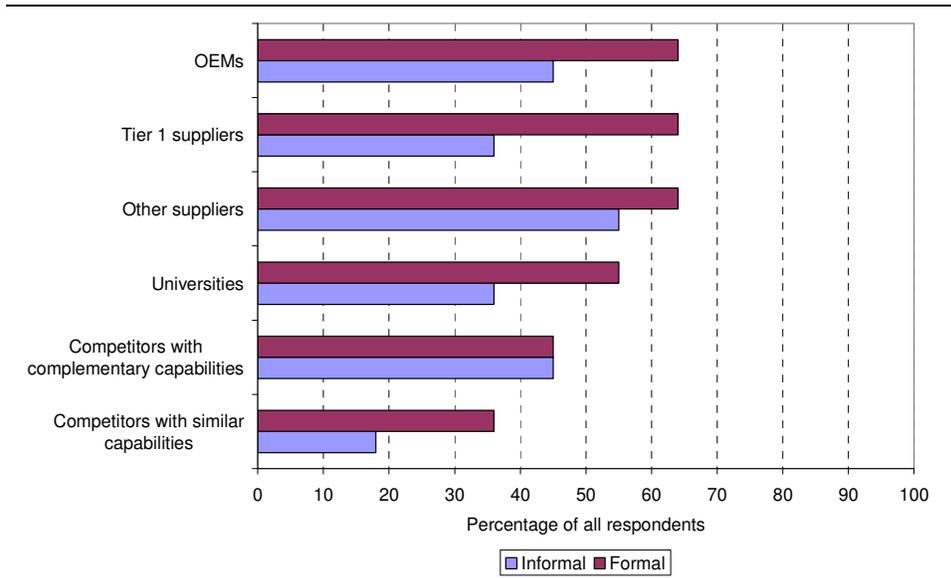
– Top tier IDE company D

- 9.4.13 Continual process innovation is crucial for most companies in the sector, regardless of their business model. The need to meet the budget constraints of customers and meet growing competition from low-cost regions demands innovation in processes to do things faster, cheaper and better. In addition, because the IDE sector is essentially involved with 'technology transfer' through the solving of problems, the firms must continually innovate to derive capabilities and processes that customers will require to solve their internal problems.
- 9.4.14 In order to reduce costs, firms are finding ways to link process innovation with accessing lower cost resources to sub-contract more routine work.

Collaboration

- 9.4.15 The innovation system framework within which this study is embedded focuses its attention on linkages between players in the system. In the automotive IDE sector, all the companies surveyed undertook some form of collaboration, either formal or informal. These collaborations tend to be for specific commercial ends, e.g. to jointly fulfil a contract. More open-ended collaborations are rare in this sector since commercial pressures are intense, information is guarded zealously and trust is built slowly. Formal collaboration with OEMs and the supplier base was the most common form, with 64% of firms undertaking such collaboration. Informal collaboration was most common between the IDE companies and those non-Tier 1 suppliers, OEMs and competitors with complementary capabilities (Figure 9.9).
- 9.4.16 The survey of firms explored the reasons for collaboration. The ability to expand the range of expertise and products offered to customers, and to access technology, information and equipment, were the most important reasons for collaboration, followed by gaining assistance in the development of specialist services and products (Figure 9.10).

Figure 9.9 Extent of collaboration with different players in the automotive innovation system



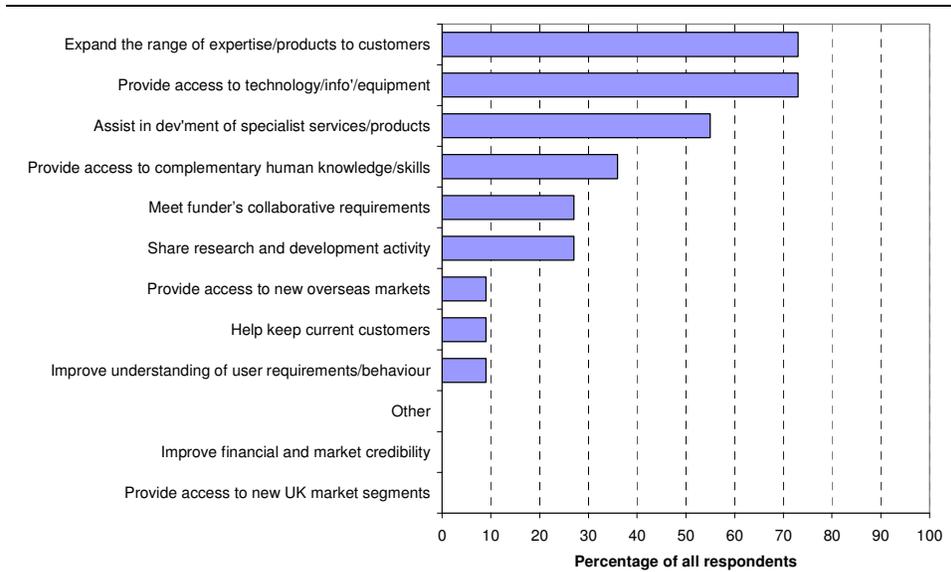
Source: PACEC survey

Notes:

Question: Thinking about your business as a whole, do you undertake collaboration with any of the following and is it formal or informal? (Please tick as many as apply)

Number of respondents: 11

Figure 9.10 Reasons for collaboration (percentage of all respondents ranking factor as very significant or crucial for their competitive advantage)



Source: PACEC survey

Notes:

Question: What are the main reasons for collaboration in your main market segment? (Please select as many as apply and score each from 1-5 in order of importance for your competitive advantage)

Number of respondents: 11

Collaboration with customers

- 9.4.17 OEMs are increasingly insisting upon collaborative working relationships with the design teams from the IDE firm. It is not uncommon for parts of the design teams to be co-located either at the site of the OEM, or at the site of the IDE company and to involve active participation from both design engineering teams.
- 9.4.18 IDE companies tend to be of the view that OEMs could realise substantial benefits from a collaboration, rather than sub-contracting model for the outsourcing relationship. IDE companies are able to view the OEM's design process from a new perspective. In this manner, through close collaboration with the IDE companies, OEMs can realise potentially substantial process and, hence, productivity improvements. They argue that the application of 'cost-down' to design outsourcing does not help OEMs achieve their cost and quality objectives.

Panel 9.1 Ricardo – GM Collaboration

What happened?

- In 1998, GM realised that it needed a contemporary 3.6 litre gasoline V6 engine that could be deployed across its global product lines.
- At the time, GM lacked the internal resources, due to existing powertrain commitments. It also needed the engine to be designed in a much shorter period of time, compared with normal in-house engine development programmes. It decided to engage collaboratively with Ricardo to co-design their new 'Global V6 engine'.
- Playing to Ricardo's advantage was its unblemished previous track record working with GM on other gasoline engine programmes.
- Going against the norm, GM and Ricardo assembled a team of their best engineers to collaborate on the project at a centre, known as Plymouth Technical Centre, near GM Powertrain headquarters at Pontiac, Detroit.
- The engineers had the autonomy and authority to establish their own development processes and were both challenged and incentivised to meet highly visible deadlines.

What were the results?

- Delivered a world-class product, feature-rich in new technologies, and set new standards in performance, quality and time to market.
- The collaboration with Ricardo had resulted in benefits to GM over and above the contractually agreed design of the new engine. It resulted in a number of improvements to GM Powertrain processes which were incorporated back into other in-house GM Powertrain programmes. Many lessons were learned, including team-working principles that were developed at Plymouth, leading to overall productivity and efficiency gains back in-house at GM.

Source: Ricardo Quarterly (2005) "It's all about the engine", Volume 4

9.4.19 OEMs have yet to be convinced by this argument, believing by and large that in-house design capabilities are sufficient for their purposes, and that the IDE sector can be treated as suppliers of commodity services.

9.4.20 European and particularly Japanese OEMs have historically operated a more open outsourcing model than their US counterparts, although this may be changing (as is illustrated in Panel 9.1). UK OEMs only operate a comparable collaborative relationship with the top UK IDE firms. The benefits to the IDE firm of close collaboration with their customers include gaining valuable insights into OEM processes, and trends in their technologies and final customer preferences that help them both serve the customer better and utilise resources more efficiently. In addition, the successful integration of an innovative technology through a collaborative relationship with the customer can act as a significant market tool for the IDE company and can substantially boost its reputation not only within the collaborating customer, but within the wider industry.

Accessing new markets

9.4.21 Collaboration also facilitates entry into new markets where the IDE firm has little or no previous presence. By partnering with a local firm, they are able to gain advantages such as crucial knowledge of cultural working practices, access to the skills base, and to customers. In addition, regardless of their reputation in their existing markets, prior to entry they may have little or no reputation in the new market. Partnering with an established local design partner (whether OEM, IDE firm or other) with a strong reputation allows them to overcome the reputational barrier while they develop their own.

Setting the standards

9.4.22 New technologies are increasingly complex and expensive to develop, and their development is dependent on collaboration. In addition, there are typically a number of different technological solutions to the same problem. One example is alternative fuel technology, where collaboration between powertrain competitors, OEMs, fuel suppliers, and government regulation and innovation policy teams, helps decide the technology development path and agree standards.

9.4.23 Once the division of labour and policy issues have been decided, design firms tend to develop the technology on their own, but view collaboration as making an extremely important contribution to reducing the risk of investing in new technology.

9.4.24 Collaboration takes up real resources and the benefits take time to be realised. Many of the smaller companies interviewed confirmed that they were reluctant to incur the costs of collaborating e.g. with universities, which suggests that only the larger IDE companies are capable of realising the gains from this kind of collaboration.

Two mechanisms for overcoming interface complexity problems

9.4.25 The interaction of different engineering teams is required in the design of a vehicle to ensure that different modules work seamlessly with each other. This requires that interfaces between modules be well designed, but as the complexity of the technology increases, and as electronics systems allow for much greater integration of the functions of different modules, the interface design challenge grows rapidly. Under these conditions, design outsourcing demands that suppliers have a clear understanding of the overall project and, as well, good communication with the system designers of the OEMs. In many cases, the OEM will insist upon collaborative working between the design teams as part of the contract.

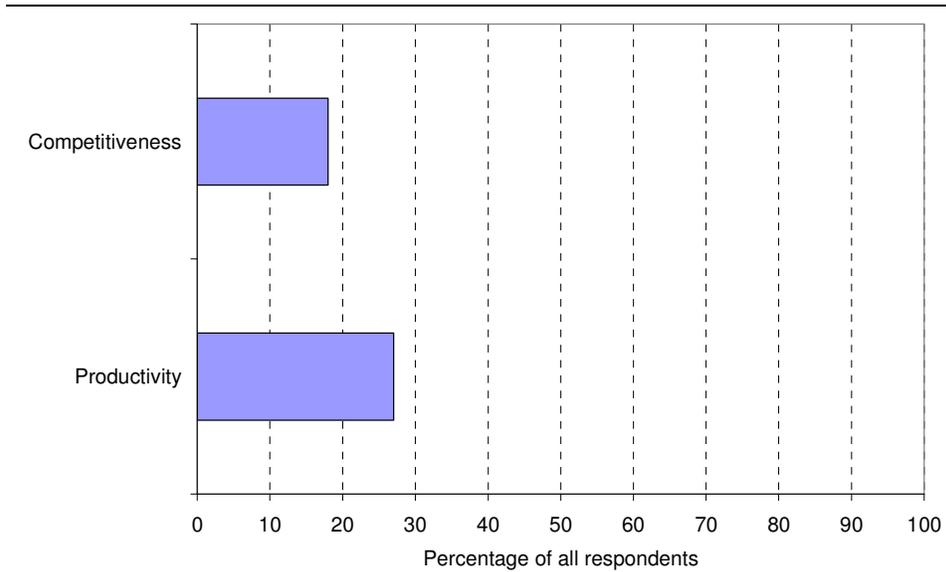
Location: geographical proximity, offshoring and outsourcing

9.4.26 To this end, OEMs may require suppliers to locate near in-house design teams. Frequent face-to-face interaction is necessary to overcome the interfacing and compatibility problems which characterise the development of complex products, particularly as design outsourcing involves some loss of control.

9.4.27 OEMs in different regions have different beliefs as to the benefits of geographical proximity. American OEMs are the strongest proponents of co-location. Most UK and European IDE companies have offshore offices in Michigan near the 'big 3' OEMs, although they may also have operations in other parts of the US. German OEMs also favour proximity. Co-location normally only involves relevant teams, not the entire company. Thus, Rousch has sites spread around the US, and FEV is based in Aachen, Germany, where the nearest auto manufacturing centres are Cologne and Düsseldorf, 65 and 85 kilometres away.

9.4.28 The OEM perception of the benefits of close geographical proximity is not universally shared by the IDE community. The survey of firms revealed that only 18% and 27% of respondents believe that close geographical proximity is very significant or crucial to their competitiveness and productivity respectively (Figure 9.11). The interview programme confirmed that IDE companies located operations near customers because of customer preferences, not because they considered it beneficial. On the contrary, it was thought that close proximity could have adverse effects on productivity through unnecessary interference in the design process.

Figure 9.11 Importance of geographical proximity to competitiveness and productivity.



Percentage of respondents ranking it very significant or crucial to competitiveness or productivity
 Source: PACEC survey

- 9.4.29 UK IDE companies better understand the need for proximity to Far East OEMs that they are helping to acquire the design and manufacturing capabilities they currently lack. They are opening offshore design offices near these customers to facilitate access to important markets and other lower cost resources. One consequence for UK design activity is that this could reduce the amount of design undertaken domestically. A number of the large IDE consultancies interviewed confirmed that their aim was to develop their offshore locations, rather than their UK design operations.

- 9.4.30 OEMs are asking IDE companies to make greater use of design resources in lower cost regions. Some UK IDE firms claim that the cost savings are often much less than might be expected, because firms fail to take into account higher monitoring, communications, project management and local set-up costs. The work currently offshored tends to be more routine and lower margin, but capabilities are expected to improve rapidly.

- 9.4.31 Many of the large IDE consultancies interviewed have facilities in Detroit, Germany and small offices in China. China and India present significant opportunities for IDE firms, providing they have the capabilities to operate in these markets. UK IDE firms perceive opportunities in China as short-term because they expect there will be rapid acquisition of design capabilities in that country. UK companies are participating in this market because if they do not, others will, and it gives them respite from the tough UK market conditions in which to plan.

Supplier networks

- 9.4.32 The second method for overcoming the problem of design complexity is to develop long-term relationships with a smaller number of design companies. In this manner, the OEM reduces the complexity and cost of managing the interface between many different suppliers of design which, in turn, reduces costs. In addition, suppliers gain knowledge of the OEM's systems and how they integrate together, thus allowing them to ensure complete compatibility between designs. This reduces the overall transactions cost of outsourcing the project. By being able to offer the complete solution that minimises the complexity of interfacing with the other modules of the vehicle, companies can potentially improve their competitive advantage.

The problem of asymmetric bargaining power between customer and provider

- 9.4.33 The research suggests that the asymmetry in bargaining power has an important influence on company strategies.

Commoditisation of design engineering

- 9.4.34 IDE companies argue that some OEMs are using their bargaining power to effectively commoditise their services. They claim that the hourly rate has become the main criterion for supplier selection, not the value added in terms of efficiency savings, and that this is short-sighted and damaging to the innovation system. The extent to which this is true varies by service provider, but it is not surprising if the severe financial pressures on vehicle manufacturers lead them to minimise the short-term cost of design outsourcing, even if this is at the expense of longer term design supply needs.
- 9.4.35 There is evidence that Japanese OEMs manage supplier relationship very differently, investing in longer term relationships based on sharing the profits from innovation. This does not provide an instant escape route for the UK design sector because it can take several years to build up a relationship with a Japanese OEM to the point where the potential suitor might be asked to bid. Also, however desirable the profit-sharing model might be, it only works if there is commitment and trust on both sides. The current behaviour of Western OEMs suggests that they have either not been able to build up such relationships, or not needed to.
- 9.4.36 A longer term threat to the bargaining position of the UK design sector which has historically specialised in powertrain, is the increased importance to consumers of electronics-based functionality (e.g. infotainment systems, safety features) and emissions and fuel economy. While these preferences are inherently tied to powertrain technology and calibration, consumers are much less likely to be concerned with the 'brand' of engine. This is leading OEMs to increasingly collaborate on engine design, with the result that the same engine can end up in the vehicles of competing OEMs. IDE companies involved in powertrain are looking for ways to enhance their product offering, e.g. using electronics to improve performance, but they then begin to compete with large Tier 1s.

Downward pressure on prices

- 9.4.37 This downward pressure on prices is particularly acute for both the US and European OEMs, as they seek to reduce their cost base. The shift of the outsourcing decision from engineering to procurement departments, as OEMs pursue cost reduction strategies, has led to the primary determinant of the decision to outsource shifting from quality/competence to lowest cost. With very little leverage and constant threat from competitors who are willing to meet these lower prices (whether they be low-cost IDE companies, or Tier 1 companies who can sink the design cost in return for the manufacturing contract), IDE companies can do little to raise their prices.
- 9.4.38 However, this trend is not consistent across the OEM base. Japanese OEMs take a different approach to their suppliers. While US OEMs drive down prices in their effort to achieve cost reduction targets, potentially sacrificing quality, the major OEMs from the Far East prefer to invest in their design suppliers to ensure that once a relationship has been established, it will exist for the long-term. One large IDE company in the powertrain market claimed that a bid was rejected by a Japanese OEM because the price was too low and that they would not be able to make enough profit on the project to ensure future survival. This long-term strategy, based on paying premium prices for engineering services, can be used by the highly successful OEMs to ensure quality. However, they can only employ it because they currently do not face the same budget constraints as their US counterparts.
- 9.4.39 The differential outsourcing strategies of the customer base has implications for the strategic focus of the IDE sector and suggests a 'winner takes all' strategy with the companies that can break into the design supplier network of the cash-rich Japanese OEMs likely to be the most successful. However, given the immaturity of the Japanese outsourced design market, the high margins and long term relationships with Japanese OEMs may be short-lived.

Pressure to provide contract labour

- 9.4.40 OEM cost reduction programmes and tight control of headcount have meant that there could be insufficient internal design resources e.g. on new development projects. This is considered to be largely a capacity problem, although there is also an awareness that some capabilities have been lost. One response has been to engage IDE companies to supply engineers on a contract basis to work on-site with in-house teams. This has been common practice in the US for a long time. It has been claimed that OEMs are using this policy to minimise knowledge leakage, while maximising their own learning, although this is disputed.
- 9.4.41 While there is no reason that the labour contracting business cannot be profitable, the IDE companies are under no illusion that this represents a sustainable core business model. There is a risk over time of a loss of capabilities and experienced engineers. Most of these companies and their employees are in business to provide design engineering solutions rather than contract labour.

Strategic positioning in the design chain

- 9.4.42 The extent of bargaining power asymmetry is a function of the position of the company in the design chain. IDE companies which supply services at the concept stage tend to be better positioned to secure a share of the downstream design work than those offering services for later stages, such as testing and prototyping. Companies that provide the complete range of capabilities are in a stronger bargaining position.

Ownership by Tier 1s and OEMs

- 9.4.43 Many IDE companies are independent, but some are owned by much larger companies, typically Tier 1 supplier or automotive OEMs. TRW Conekt is owned by TRW Automotive, a Tier 1 supplier of automotive safety systems; Mahle Powertrain is owned by the German Tier 1 Mahle, a supplier of products relating to combustion engines and peripherals; and Lotus is owned by the Malaysian OEM, Proton.
- 9.4.44 Ownership by automotive OEMs puts off some customers because of worries about information leakage, in spite of 'Chinese walls' and tight security. Tier 1 ownership is much less of a problem. Tier 1 suppliers can offer access to resources and routes to markets not normally available to small companies. Access to a global network of research, manufacturing, sales and distribution operations greatly reduces set-up and entry costs, and builds the reputation of a design company. The parent benefits from access to an innovation culture that is often missing in component suppliers.

The strategic implications for the design engineering sector

- 9.4.45 OEM price pressure and reversal of outsourcing strategy has led to changes in the strategies of IDE companies.

The one-stop shop: a 'winner-takes-all' strategy

- 9.4.46 The first strategic profile emerging is the 'one-stop-shop'. In this strategy, companies aim to provide the full project capability across one or more complete modules or systems, tackling the full vehicle if needed. This strategy is predicated on a view that the overall benefits to the customer from dealing with one provider of design for the complete vehicle, in which the provider is best-in-class for some but not all of the vehicle modules, exceed the benefits that the customer would enjoy if they secured best-in-class providers for each individual module. The perception of the increased benefits stems from, amongst other factors, the reduced cost and performance improvements of designing the complex interfaces in-house, the reduced transactions costs of managing multiple suppliers, and increased control of information leakage. Another attraction of the one-stop-shop strategy is that the IDE firm can develop potentially insurmountable barriers to entry to the full vehicle design service provision market.
- 9.4.47 This strategy requires a long-term view as a crucial part involves striving to become the design supplier of choice for an OEM and developing a long-term relationship with

them. Not only does this secure future projects, but it reduces the fixed learning costs that new design suppliers must sink at the beginning of the project, in becoming accustomed to the OEM's systems, processes and interfaces. In addition, trust is built up between the parties reduces the transactions costs in outsourcing complete design projects.

- 9.4.48 The importance of selecting the right customer is paramount. Customers from different regions have extremely different attitudes towards their suppliers. It is said that the successful Japanese OEMs are more interested in profit sharing with their suppliers than their European and American counterparts. However (anecdotally at least), the amount of outsourcing by Japanese OEMs is significantly less suggesting a trade-off between margins per project and volume of work. European and Japanese OEMs tend to outsource complete modules, while the US OEMs tend to focus on pressuring IDE companies to provide contract labour to work on-site. Within each of these types of customers, however, there are only a limited number of buyers of IDE services.
- 9.4.49 The difference in outsourcing preferences between customers means that firms must be flexible enough to be able to target their IDE service to the particular needs of their customer. In addition, because of the perceived need to be near their customer base in order to access the design supplier networks, these companies tend to expand globally and locate outposts in the regions local to the customer. Given the emergence of India and China as rapidly growing end-user markets, and the desire by indigenous Indian and Chinese OEMs to outsource design work while they climb the development ladder, these regions cannot be ignored by the IDE firms pursuing a one-stop-shop strategy.
- 9.4.50 These factors suggest that firms pursuing one-stop strategies are playing a 'winner-takes-all' strategy, with the firm able to access the OEM network that offers the most profitable combination of high margin and volume, surviving. The limited amount of buyers also suggests that market capacity can accommodate only a small number of winners, making the game being played when pursuing the one-stop-shop strategy highly risky.
- 9.4.51 However, this strategy is not open to all firms in the sector. Because the strategy is associated with undertaking full projects on complete modules over the entire vehicle, IDE firms must be able to offer *capabilities* that customers lack, rather than simply act as capacity-fillers. This, in turn, suggests that such companies must be on or near the technology frontier, close to the leading edge research in the particular market niche, which in turn requires significant investment in research and development. They must also possess the necessary reputation that can support their claims that they can deliver full-vehicle solutions. This implies that the past experiences of the company are important in determining the success of this strategy. All of the above suggest that there is a critical mass in terms of size, below which the one-stop-shop strategy cannot be considered a viable option.

The sub-module specialists: pressure to provide contract labour

- 9.4.52 The alternative strategic profile emerging is the sub-module specialist. Such a profile dictates that companies focus on providing the capabilities for a particular sub-module or sub-system of the vehicle. This appears to be a second-best strategy for those companies that cannot overcome the barriers to becoming a one-stop-shop offering the complete set of capabilities across an entire module.
- 9.4.53 The potential market for IDE companies that pursue such strategies is, therefore, different from those companies that pursue one-stop-shop strategies. Sub-module specialists compete in highly segmented markets, focusing on the technology for an individual components rather than complete modules. They will, therefore, lack the detailed knowledge of the interfaces that the one-stop-shop providers have accumulated. The customer base, however, remains the same and the companies will have to compete with the one-stop-shop firms to break into the most lucrative design networks.
- 9.4.54 By definition, because the module specialists provide the design solution to sub-modules of the vehicle and likely to have much less expertise in other areas of vehicle design engineering, the ability to collaborate with the systems integrator or enhance their own knowledge of the overall system becomes increasingly important. This is required to overcome the design complexities associated with the interfaces, and ensure the seamless integration of the module designed 'out-house' with the elements of the vehicle designed 'in-house' at the OEM.
- 9.4.55 The sub-module specialist will likely require a much lower critical mass to be successful. Reputation, and hence the past experiences and legacy of the company, remains very important to reducing the risk of outsourcing to an acceptable level. In addition, resources must be devoted to understanding the interface between the module and the rest of the system, either through increased systems knowledge or through collaboration with the systems integrator.
- 9.4.56 Sub-module specialists, being typically much smaller than the one-stop-shop providers are much more vulnerable to the negative effects of the asymmetry in bargaining power between themselves and the OEM. UK sub-module specialist IDE firms are increasingly being pressured into providing contract labour to fill the capability gaps in the in-house teams of the OEMs.
- 9.4.57 It is believed that this strategy is much less risky than the 'winner-takes-all' game of the one-stop-shop strategy, and there is potential for a greater number of successful firms. These firms tend to locate within the automotive clusters that maximise exposure to their main customers. This also minimises the disruption to their employee's lives.

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Appendix B Econometric Modelling

B1.1 In the report we adopt stochastic frontier methods to investigate technical and cost efficiency in the design engineering sector. In this appendix present these concepts and formally and provide technical details of our methodology.

B1.2 If only a single output is produced, departing from Debreu-Farrell measures (see Kumbhakar and Lovell 2000), an output-oriented measure of technical efficiency can be derived from the production possibilities frontier through the following equation

$$y_i = f(x_i; \beta) \cdot TE_i$$

where y_i is the scalar output of producer i , $i = 1, \dots, I$, x_i is a vector of N inputs used by producer i , $f(x_i; \beta)$ is the production frontier and β is a vector of technology parameters to be estimated. Then a measure of technical efficiency TE_i can be calculated as the ratio of observed output to the maximum feasible output

$$TE_i = \frac{y_i}{f(x_i; \beta)}$$

B1.3 If $TE_i = 1$ then producer i is efficient. Otherwise TE_i will be less than one providing a measure of inefficiency. Figure B1.1 provides a graphical illustration of this measure.

B1.4 In that case the firm will be producing at its cost frontier. In the same fashion it is possible to devise a measure of economic inefficiency CE_i given by

$$CE_i = \frac{\sum_{j=1}^M w_j x_j}{c(y_i; w_j; \gamma)}$$

Where

w_j is the cost of input j

x_j is the amount used of input j

$c(y_i; w_j; \gamma)$ is the cost frontier

B1.5 Figure B1.2 illustrates the three efficiency concepts introduced so far. In the figure a firm using 2 inputs to produce 1 output is considered. The curve is the isoquant associated with production of one unit of output with minimum inputs. The straight line is the isocost associated with the minimum cost necessary to produce one unit of output. If the firm produces over the isoquant it is said to be efficient. Therefore a measure of technical efficiency is given by

$$TE = \frac{OQ}{OP}$$

- B1.6 A firm producing over the isoquant is not necessarily cost efficient. For a firm to be cost efficient it is necessary to be producing over the isocost. Therefore a measure of cost efficiency is given by

$$CE = \frac{OR}{OP}$$

- B1.7 One could note that the three measures of efficiency are related as follows (see Kumbahkar and Lovell 2000) $CE_i = TE_i \times AE_i$

Figure B1.1 Technical Efficiency

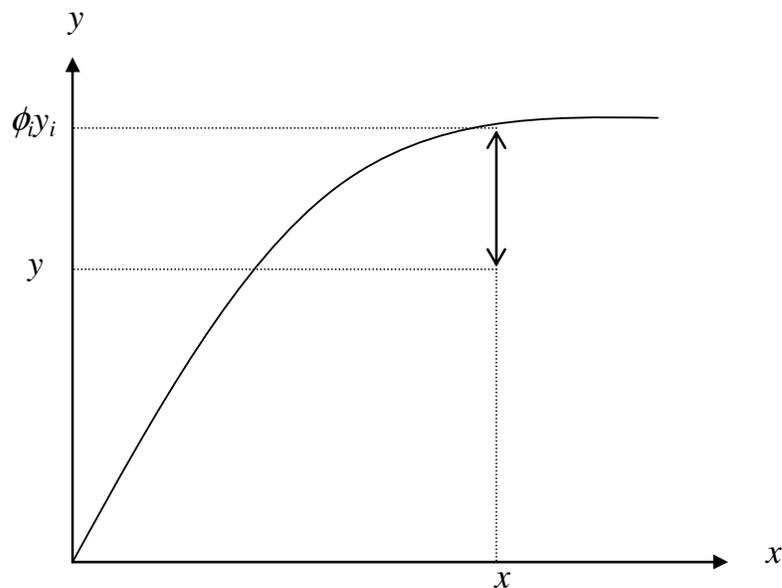
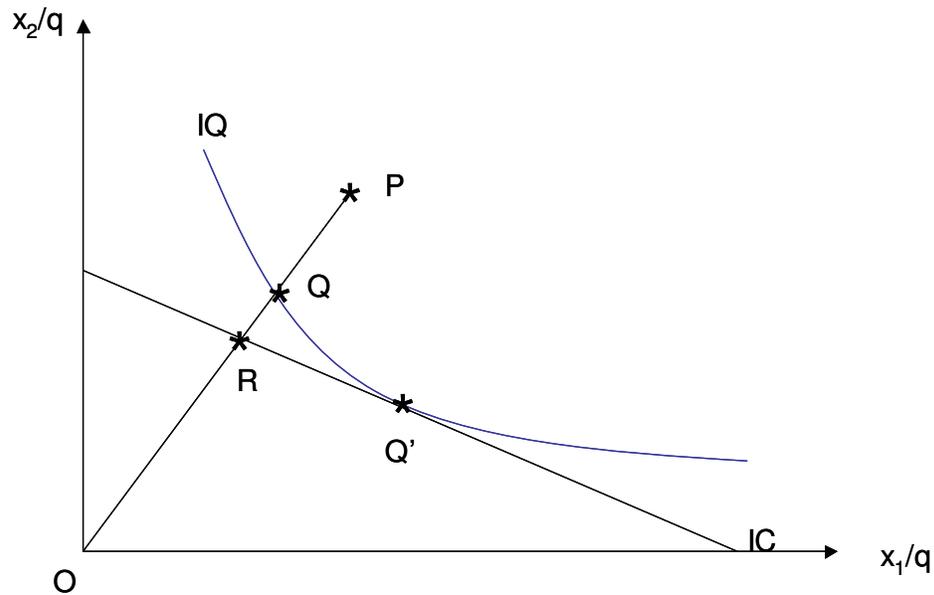


Figure B1.2 Technical, Allocative and Economic Efficiency

- B1.8 Apart from these three efficiency concepts it is possible to think of a fourth one, namely scale efficiency. As mentioned a firm could be technically and also allocatively efficient but still have the opportunity to increase its productivity by operating closer to the optimal scale. Therefore a firm operating over the cost frontier at the optimal scale is achieving economic and scale efficiency.
- B1.9 We already mentioned a measure of productivity when a firm is using one input to produce a single output. However, firms normally use several inputs to produce multiple outputs. In this case productivity measures become a bit less straightforward due to aggregation issues
- B1.10 In case of a firm using multiple inputs to produce multiple outputs we can always compute partial measures of productivity by focusing on a particular input (typically labour). However, we can also think of total factor productivity (TFP).
- B1.11 Assuming a production function, a stochastic frontier incorporates random shocks that cannot be attributed to the relationship between inputs and outputs. To arrive to a stochastic production frontier it is possible to write

$$y_i = f(x_i; \beta) \cdot \exp\{v_i\} \cdot TE_i \quad \text{and}$$

$$TE_i = \frac{y_i}{f(x_i; \beta) \cdot \exp\{v_i\}}$$

where v_i represents a random shock experienced by producer i .

B1.12 A similar formulation could be done by a cost function. The stochastic frontier model described above focuses exclusively on the relationship between output produced and inputs used in production, namely choice variables for the producers. However, the literature on productivity has emphasized that a second set of factors should be included in the analysis, which are neither outputs nor inputs but also influences the producer performance (Huang and Liu 1994, Kumbhakar et al 1991, Reifschneider and Stevenson 1991, Battese and Coelli 1995, 1997, and Sherlund et al 2003).

B1.13 These factors are exogenous to the producer choice and normally characterize the economic environment in which the production is embedded. Including exogenous factors in the analysis allows the association of variation in the producer performance with variables that are out of the control of the technological domain and shed light onto public policies concerned with technical efficiency and resource allocation as briefly outlined above, formally

$$TE_i = g(z_i)$$

where z_i is a vector of exogenous influences on efficiency.

B1.14 There are two standard functional forms used in the literature, namely Cobb-Douglas and Translog functions (Coelli et al 1998). In principle a Translog specification would be preferable given our lack of knowledge regarding the precise technological relationship relating inputs and outputs. Another alternative functional form used in the literature is the Flexible of Fourier, which extends the Translog by including trigonometric terms (see Altumbas et al 2001).

B1.15 We start writing equation a stochastic production relation as

$$y_i = f(x_i; \beta) \cdot \exp\{v_i\} \cdot \exp\{-u_i\}$$

where $TE_i = \exp\{-u_i\}$. Since $TE_i \leq 1$ is required, we have $u_i \geq 0$. Then, assuming that $f(x_i; \beta)$ takes the log-linear Cobb-Douglas form the stochastic production frontier model can be written as

$$\ln y_i = \beta_o + \sum_n \beta_{ni} x_i + v_i - u_i$$

where v_i is the two-sided 'noise' component ($v_i \sim iid N(0, \sigma_v^2)$), and u_i is the nonnegative technical inefficiency component of the error term. In studies that don't include exogenous influences (error component model) u_i might assume different positive distributions. The standard ones are the half normal ($u_i \sim iid N^+(0, \sigma_v^2)$), truncated normal ($u_i \sim iid N^+(\mu, \sigma_v^2)$), or exponential. A third assumption, normally made, states that v_i and u_i are independently distributed of each other, and of the regressors.

- B1.16 This error component model produces measures of technical efficiency and these measures could enter as dependent variable in a second stage to test the impact of exogenous influences on the variation of technical efficiency. Although a two-stage estimation could be conceived as conceptually valid (measuring efficiency first and explaining it latter) and has been done in the past (Mester 1993, 1997) there are econometric problems suggesting that simultaneous estimation would be preferable. Kumbhakar and Lovell (2000) point out that there are potentially two main problems in the two-stage estimation.
- B1.17 First, if x and z are correlated the estimates will be biased due to the omission of z in the first-stage estimation, and consequently they will be biased in the second-stage as well. Therefore, unless one has very good reasons to believe that inputs and the exogenous variables are uncorrelated this is a serious shortcoming. Second, there is an intrinsic problem regarding the distribution of TE_i . In the first stage it is normally assumed that the inefficiencies are identically distributed. However, this assumption is contradicted in the second stage when it is assumed a functional relationship with z .
- B1.18 The recent literature on exogenous effects influencing technical efficiency presents different models for which measure and explain efficiency variation simultaneously (Huang and Liu 1994, Kumbhakar et al 1991, Reifschneider and Stevenson 1991, Battese and Coelli 1995, 1997). They vary with regards to assumptions on the functional form of the production function, distribution and restriction of error components, and neutrality of exogenous influences on technical efficiency. In the Battese and Coelli model specification $u_i \sim iid N^+(\mu_i, \sigma_u^2)$ and $\mu_i = z_i \delta$.
- B1.19 Where z_i is the vector of variables (including spatially lagged variables), which may influence efficiency and δ is a vector of parameters to be estimated. Battese and Coelli adopt the parametrisation proposed by Battese and Corra (1977), replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$ to arrive to a likelihood function feasible to be estimated by maximum likelihood. The log-likelihood function of this model is presented in the appendix of Battese and Coelli (1993). The efficiency measure is calculated as $\exp(-u_i)$. Therefore positive coefficients for the exogenous variables are interpreted as negative impacts on the efficiency mean.
- B1.20 The spatially lagged variables capture the weighted average values of variables in neighbouring areas. The weights establish the proximity between data points and are built into a spatial weights matrix W . The values in W reflect our hypothesis of spatial interaction between the geographical areas, hence the main diagonal contains zeros, and the off-diagonal elements reflect the spatial proximity of each pair of areas. We follow fairly standard practice in assuming that interaction is a diminishing function of distance, with the effect decaying non-linearly as a power function. We raise distance to the power 2 to give an appropriate distance decay, and while this power is chosen a priori rather than estimated, we do estimate the parameter for the spatial lag, typically the vector WX resulting from matrix product of W and the variable X . This introduces a degree of freedom to offset the somewhat arbitrary choice of power. A

further step in the construction of the W matrix is to standardise it so that each row sums to 1. Hence

$$W_{ij}^* = \frac{1}{d_{ij}^2}$$

$$W_{ij} = \frac{W_{ij}^*}{\sum_j W_{ij}^*}$$

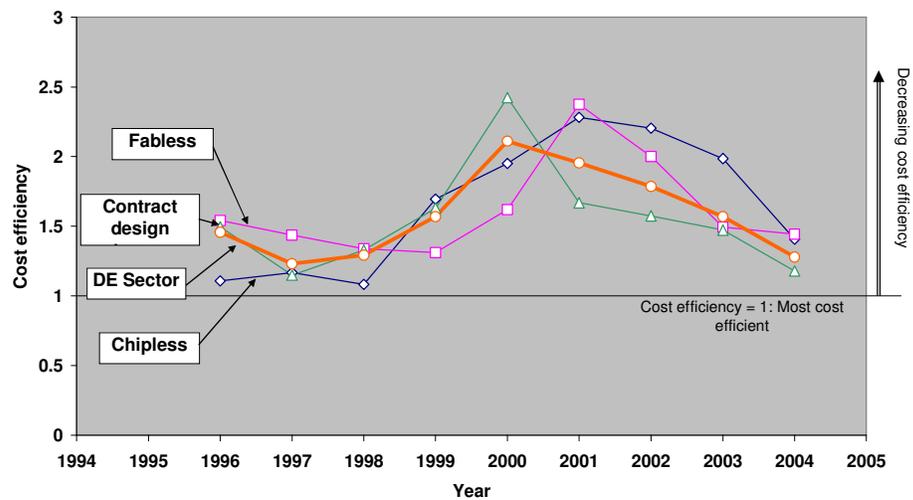
- B1.21 Standardising helps with interpretation, since the value for area J of the spatial lag, defined as the J 'th cell of WX , is then the weighted average of the values of the variable X in the areas that are 'neighbours' to J , and so its estimated coefficient can be compared directly to the coefficient for X . Also, using the standardised W matrix usefully identifies a parameter value below 1 as being consistent with a 'non-exploding' process while 1 and above leads to complex and little understood consequences for inference and estimation (the mathematical background to this and implications of spatial unit roots consistent with a parameter equal to 1 are discussed in Fingleton, 1999). One consequence of standardising is that the resulting W matrix is asymmetric, with interaction based on relative rather than absolute distance. This means that, for example, if area I has a dominant area J that carries most weight, in a different context an area at the same absolute distance as J may carry less weight because of the presence of other less distant areas.
- B1.22 Similar models can be estimated using a cost frontier and therefore examining economic efficiency. We have estimated production and cost frontiers for an unbalanced panel of firms over 1996-2004, using the maximum likelihood estimator proposed by Battese and Coelli (1993). The models allow the measurement of technical and cost inefficiencies and to explain the mean of the inefficiency measures through the impacts of exogenous variables. The equations were estimated using the software Frontier 4.1 developed by Tim Coelli.
- B1.23 The betas in the equations are the estimated parameters in the production and cost functions respectively. The deltas are the estimated parameters for the variables impacting the mean of technical and cost efficiency respectively. Negative coefficients for the deltas means that the respective variable has an direct relationship with the firm efficiency ('the higher the value assumed by the variable the higher the efficiency level of the firm').
- B1.24 In the case of a production frontier, efficiency measures will take a value between zero and one (one being the most efficient), while it will take a value between one and infinity in the cost function case (again one being the most efficient).

Appendix C Cost Efficiency Results

This appendix presents the results of the cost efficiency analysis. As mentioned in the main body of the report, we concluded that the measures of cost efficiency (which is the systematic error term from the stochastic frontier analysis of the cost frontier) not only captured the 'cost efficiency' of firms, but also the other cost inputs that were not able to be specified. **We therefore advise extreme caution in drawing any conclusions from the following cost efficiency results.**

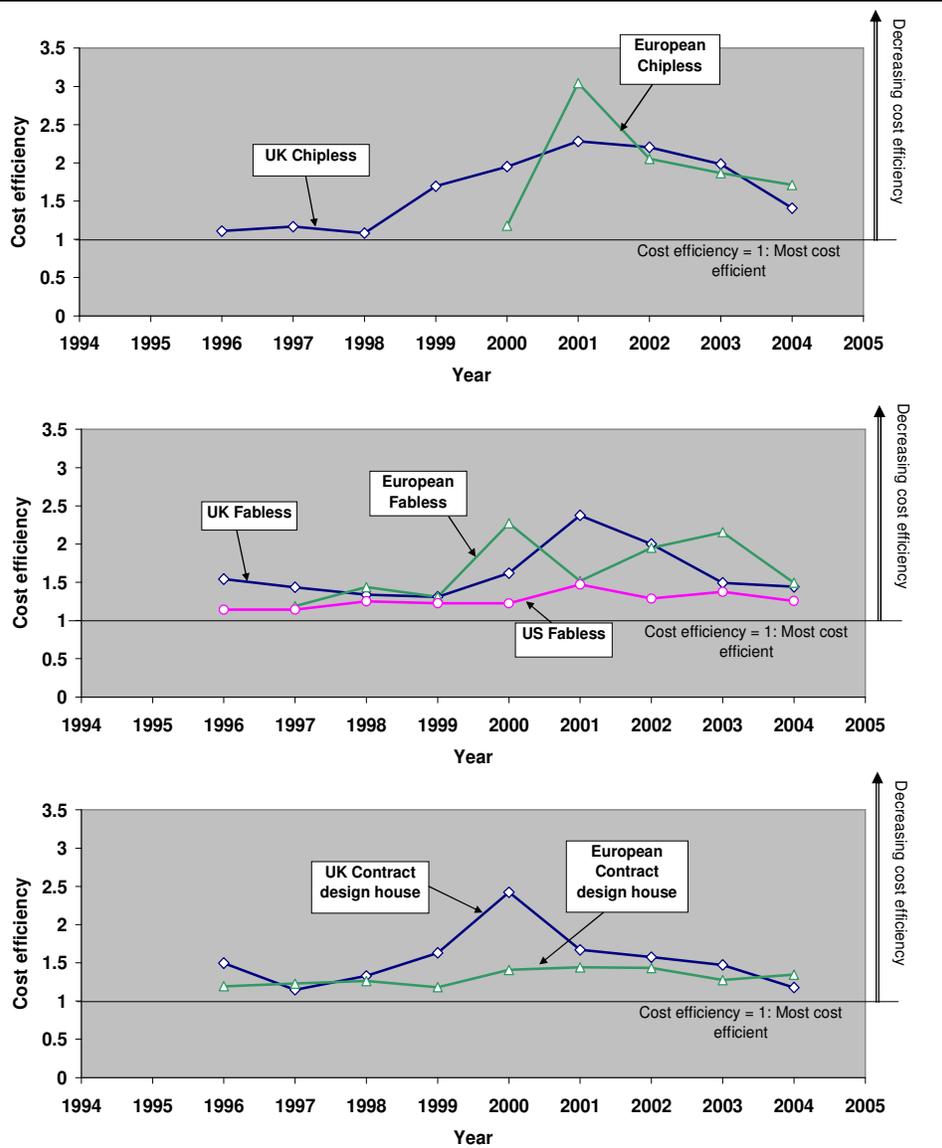
C1 Electronics Independent Design Engineering Sector: Cost Efficiency Results

Figure C1.1 Evolution of cost efficiency of the UK DE sector and the sub-sectors over the period 1996-2004.



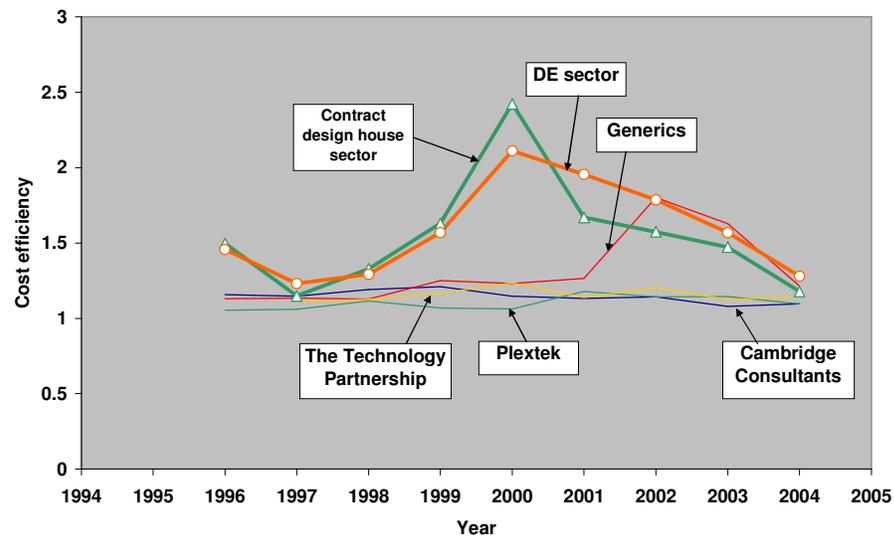
Maximum cost efficiency = 1
Source: PACEC analysis, ORBIS

Figure C1.2 Cost efficiency of the three sub-sectors of DE in different global regions



Source: PACEC analysis, ORBIS

Figure C1.3 Evolution of cost efficiency of the UK contract design house sector over the period 1996-2004. Selected companies in the Cambridge cluster



Source: PACEC analysis, ORBIS

Table C1.2 Cost efficiency analysis results using stochastic frontier analysis

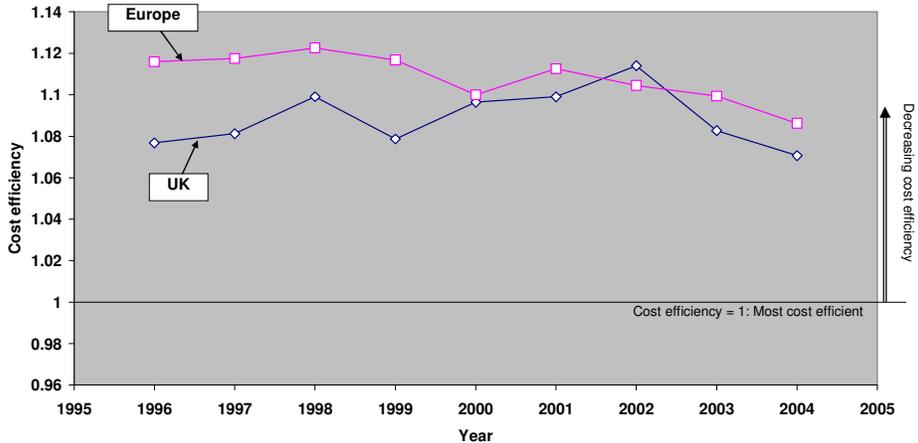
Panel (a): UK analysis			Panel (b): Cross-country		
Cost frontier			Cost frontier		
Variables	Coefficient	t-ratio	Variable	Coefficient	t-ratio
Constant	-0.88	5.07 ***	Constant	-0.38	4.87 ***
Average wages	0.91	53.13 ***	Average wages	0.98	234.83 ***
Turnover	0.40	7.20 ***	Turnover	0.06	4.07 ***
Determinants of Inefficiency			Determinants of Inefficiency		
Variable	Coefficient	t-ratio	Variable	Coefficient	t-ratio
Constant	2.62	5.95 ***	Constant	3.34	9.65 ***
Turnover	-0.91	23.78 ***	Employment	1.30	16.27 ***
Employment	1.09	15.92 ***	Turnover	-1.11	22.50 ***
Contract Design Dummy	-0.05	0.45	Contract Design Dummy	-0.85	4.08 ***
Fabless Dummy	0.17	1.62	Fabless Dummy	0.20	1.28
Others Dummy	-0.08	0.65	Others Dummy	-1.10	3.61 ***
Age dummy <10	0.56	3.57 ***	Age dummy <10	0.62	2.64 ***
Age dummy >11<25	0.17	1.18	Age dummy >11<25	0.29	1.35
Non-UK offices dummy	0.48	3.85 ***	UK dummy	0.22	1.83 *
University Impact	0.00	0.76	US dummy	-0.01	0.027
Patents	-0.02	2.64 ***			
Total employment	0.00	0.62			

Note: ***: 1% significance; **: 5% significance; *: 10% significance

Source: PACEC analysis, ORBIS

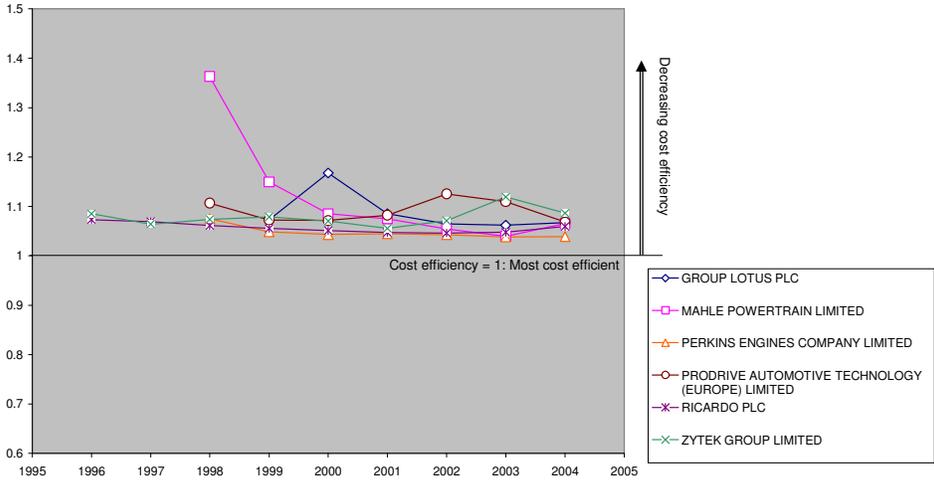
C2 Automotive Independent Design Engineering Sector: Cost Efficiency Results

Figure C2.1 Evolution of the cost efficiency of the UK and European DE sector over the period 1996-2004. Maximum cost efficiency = 1.



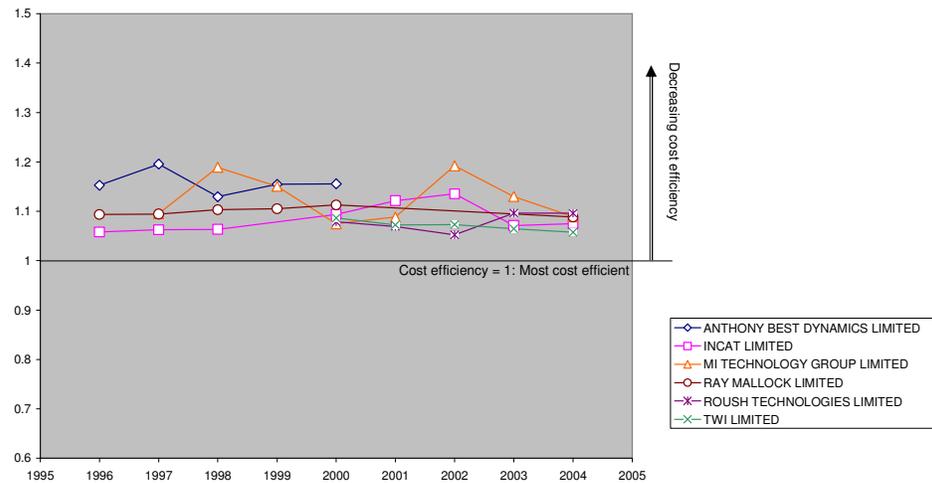
Source: PACEC analysis, ORBIS

Figure C2.2 Evolution of cost efficiency of selected companies in the automotive DE sector over 1996-2004.



Source: PACEC analysis, ORBIS

Figure C2.3 Evolution of cost efficiency of selected companies in the automotive DE sector over 1996-2004.



Source: PACEC analysis, ORBIS

Table C2.2 Results of the cost efficiency analysis

Cost function		
Variables	Coefficient	t-ratio
Constant	-1.55	-10.62 ***
Average wages	0.17	3.23 ***
Turnover	1.07	79.87 ***
Determinants of Inefficiency		
Variable	Coefficient	t-ratio
Constant	0.43	1.31
Turnover	-0.27	-4.18 ***
Employment	0.26	3.87 ***
Total employment	0.00	3.67 ***
University Impact	0.00	-1.09
Patents	-0.02	-2.84 ***
Non-UK offices	0.07	1.84 *
Age dummy <10	0.21	2.63 ***
Age dummy 11 < 25	0.18	2.45 **

Note: ***: 1% significance; **: 5% significance; *: 10% significance

Source: PACEC analysis

Appendix D The ORBIS Database

D1 Introduction to the ORBIS Database

- D1.1 The study was provided access company level data from the ORBIS database produced by Bureau van Dijk (BvD). ORBIS contains financial and other information on both publicly quoted and private companies. Crucial to this study is its international dimension, with the database containing information on over 35 million companies worldwide. BvD claims that the data should be comparable across countries and provides facilities within the user interface for cross-country comparisons and for downloading data in a constant exchange rate.
- D1.2 The ORBIS search facility allows for easy searching by, among other things, different types of industrial classification (e.g. UK SIC codes, US NAICS etc.), by geography, and by ownership type (public, private etc.). In addition ORBIS provides a short summary of core activities for many (but by no means all) companies which can be searched using a key word search.
- D1.3 ORBIS also allows for the download of data in user-specified formats which facilitates the data gathering phase.

D2 Limitations of the ORBIS Database for the DE Sector Analysis

Data coverage

- D2.1 While the ORBIS database provides details on 16 million companies, the data coverage for each company varies greatly. Inevitably the comprehensiveness of the data depends on the accounting reporting regulations of the country in which the company is registered. Typical factors affecting the data coverage include the size of the company, country of registration and its ownership type (public or private).
- D2.2 Unsurprisingly, publicly traded companies typically provided the most data. However, due to different accounting reporting standards in different countries, variables may be systematically missing (e.g. cost of employees for US publicly quoted companies).
- D2.3 Private companies in many countries were found to have good data coverage with most of the key variables available. However, a number of countries presented particular problems due to their reporting regulations. These included private US companies, who appeared not to have to submit financial accounts to any federal or state-level body. Extremely limited data were therefore not available in ORBIS for such companies (typically including only the number of employees, and occasionally turnover). Private German companies also systematically provided limited data.
- D2.4 Very small companies systematically had poor data coverage regardless of the country of registration.

Searching by SIC codes and key words

- D2.5 While the SIC code facility was useful, it was severely limited for analysing the design engineering sector. This was because the DE sector straddles a number of different SIC codes, none of which are mutually exclusive. SIC code searches of the key SIC codes which contain DE companies (e.g. 74.2) would therefore only help reduce the number of companies that had to be manually checked to ensure true fit within the boundaries of the sector. In addition, a number of design engineering companies took the SIC code of their customer's main sector which meant that the SIC code searches had to be widened to include these (potentially large) sectors.
- D2.6 The key word search facility also allowed for more efficient searching of companies. However, this was more reliable at identifying larger companies as the descriptions of small companies were typically too vague to be of much use.

Data cleaning

- D2.7 Once the data were downloaded, it was necessary to clean the data. In a number of companies it was found that operating profits equalled revenues. This abnormality was traced to a reporting error within ORBIS which we now believe has been corrected.
- D2.8 Significant amounts of time also had to be spent understanding outliers in the accounts. For example, a number of companies were found to experience sudden drops in operating profits for a single year. In one instance this was traced through obtaining the annual report, to a one-off payment into their pension fund. For the smaller companies, tracing such problems was extremely difficult due to lack of detail in any explanatory notes to the financial accounts.

Implications for the Econometric Analysis

- D2.9 The prevalence of small, private companies in the UK, European and US design engineering sectors meant that it was not possible to obtain data for many of the companies. Therefore, this severely constrained both the size of the sample (in terms of the number of companies), and the number of variables that could be used in the econometric analysis.