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Understanding Innovation: How firms innovate and what governments can do to help – Wales and Thuringia compared

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Contents

List of tables

List of figures

Executive summary

Opto-electronics is a major world industry, in which Germany and the UK rank 3rd and 4th after Japan and the USA. It is characterised by clusters of firms in close proximity to centres for scientific research. At the same time the industry reflects the globalisation of the world economy, with high levels of cross-border trade and international collaboration for new product development. Between these two influences – the attraction of clusters and the realities of internationalisation – national governments support innovation through various infrastructure policies.

This study looks at the relative impact of these three levels on the innovation of firms in two regions of the UK and Germany: Wales and Thuringia. While both are characterised by active regional policies, they provide a striking contrast in the orientation of their opto-electronics industries and the thrust of regional policy. The Welsh firms are generally older and more international, and regional policy seeks to build on this. In Thuringia, on the other hand, the aim is in keeping with that elsewhere in Germany: to develop a regional technology system that stresses the exchange of technology between the scientific infrastructure and innovating firms.

Through a series of 14 case studies – six in Wales and eight in Thuringia – this study uses the innovation processes and experiences of the firms themselves as a touchstone to assess the effectiveness of governmental policies. In doing so, it views innovation through a series of models:

1. A framework that describes innovation as an interactive sequential process, from initial idea to the marketing of a product
2. A theory of knowledge creation, which stresses the role of tacit and explicit knowledge through the various stages
3. Three key management practices, which enable firms to successfully navigate the process of innovation:
   (i) Allow the market to drive the innovation process (‘demand articulation’)
   (ii) Develop a strong intelligence-gathering capability, as a source of new ideas
   (iii) Develop collaborative research links, especially outside a firm’s own industry.

The findings at this level of analysis highlight interesting differences. Product development in the Welsh firms has involved close relations with a small number of international companies, with the Welsh firms using their design skills to solve problems identified in association with their customers. In Thuringia there is less evidence that this kind of demand articulation forms part of the innovation process, except for the very largest firms. Instead, it appears to be more of a ’bottom-up’ approach, in which firms solve technical problems for industrial and scientific applications (often in partnership with other research centres), with the wider market opportunities to be developed later. This is an indication that firms’ innovative behaviour depends significantly on their maturity and size.

The approach to intelligence gathering also differs. The Welsh companies are more inclined to link into large customers and research institutions outside the region (which gives them access to global markets), while companies in Thuringia are deeply embedded in local networks and take advantage of the local research network in a more informal face-to-face way. They also use the local (and national) research infrastructure to do collaborative research on new product development to a much greater extent than is the case in Wales.

The cases reveal a great deal else about collaboration. First, collaboration in the customer supply chain is generally much more important than collaboration between opto-electronics companies themselves, but firms need to stay in control of these relationships. Second, intra-regional and extra-regional networking serve different purposes, which reflect the changing needs of firms as they mature, but localised clusters may have renewed value to firms in their later stages of development, when they bring together different technologies that can be combined. Third, the role that large firms play in local networks can be crucial.

The result of these comparisons is to highlight a succession of differences between 'young innovators' (predominantly the Thuringian firms) and 'mature innovators' (the Welsh firms), and the challenges that face the latter in remaining innovative – a challenge, in effect, to become 'post-mature innovators'. Given the mature firm's more complex situation in local, national and international networks and its greater reliance on 'distributed R&D', this means overcoming problems of tacit and explicit knowledge in working with partners and seeing how far electronic data exchange can help in this.

The study then assesses government policies on innovation in relation to these differences and in terms of what the firms themselves say. A key distinction is made between policies that provide resource support and those designed to promote learning through knowledge networks (including technology transfer). The result is a series of challenges to government about the adequacy of the innovation system:

- Does the system take account of the different needs and capabilities of firms at their different stages of development, and does it address the whole range of these?
- Does it recognise the way firms operate through markets, hierarchies and networks, and does it respect these as alternative routes for collaboration? That is, does it work with the grain of firms' own structures and behaviour, and with commercial relationships, which are partly a function of national systems of corporate governance and partly of their stage of development?
- Does it meet firms' needs to participate in multiple overlapping networks as a stimulus to innovation?
- What kinds of initiatives and structures might help with the challenge of accommodating tacit and explicit knowledge in the course of the innovation process?

While arguing that policy should be sensitive to the specific needs of and differences between firms, therefore, the key message is that policy needs to avoid being trapped in these alone – whether it is being geared to the needs of mature firms in Wales, or to those of new start-ups in Thuringia. A broad frame of reference, taking account of the experiences of innovating firms across different stages of development, is necessary if public policy is to be responsive to the needs of all kinds of firms and to the long-term needs of an innovating economy.

1 Introduction

1.1 High-technology industry and government policy

As mature industries decline, new high-technology sectors become increasingly important. Not only do they generate new products, they also help regenerate traditional industries through new processes and advanced product features. Governments for many years have therefore been concerned with promoting the growth and development of high-technology sectors, through policies for industry, science and technology.

Over the past 20 years the emphasis of these polices has shifted (Boekholt and Thuriaux, 1999). In the late 1980s the idea of **'national innovation systems'** came into use and gained rapid acceptance. This saw innovation arising out of the networks of relationships among different actors – firms, the research infrastructure, public and private institutions – within the boundaries of the nation state (Freeman, 1974, 1995; Lundvall, 1992; Metcalfe, 1995; Roelandt and Hertog, 1999).

These institutional relationships, and the cultural values they embody and promote, differ significantly between countries. The idea of national innovation systems therefore helped to explain the comparative performance of countries and was attractive to governments in highlighting elements they could influence and change. By encouraging analysis of comparative national systems (Nelson, 1993), it focused attention on the most 'successful' economies – the USA, Germany and Japan – to see what could be learnt from them.

During the 1990s, however, the theory of national innovation systems was undermined from above and below. On the one hand, the **globalisation** of the world economy, through the activities of far-flung multinational companies and networks of co-operation between independent firms, suggests that national systems are diminishing in importance (Dunning, 1993). Multinational companies can locate their R&D activities in countries that are particularly strong, and can move technology and innovations between many different locations (Ghoshal and Bartlett, 1990; Cantwell and Harding, 1998).

On the other hand, European work on 'industrial districts' during the 1980s, along with more recent American work on 'clusters', emphasises the importance of the regional level (Brusco, 1990; Scott, 1988). This suggests that **regional clusters** of firms, within the same or related industries, are a more appropriate foundation on which to build a sustainable national policy for international competitiveness in high-technology sectors. While countries demonstrate strengths in particular industries and technologies, these are often localised within regional clusters of firms and local institutions (Porter, 1990). One consequence is that the analysis of national systems of innovation may need to be supplemented by reference to regional systems of innovation (Casper and Vitols, 1997; Cooke et al., 1997).

Combining these perspectives, recent work on high-technology regional clusters has emphasised the need for firms to be open to global networking (Cooke, 1995) and for analysis of regional clusters to take account of the way these are embedded in international networks (Amin and Thrift, 1992; Garnsey and Cannon-Brookes, 1993; Hahn and Gaiser, 1994; Keeble, 1994; Ganter, 1997). Scott (1993) argues:

> 'Much of the contemporary world economy can be seen as a mosaic of regional agglomerations (marked by localised transactional networks) embedded in far-flung systems of national and international transacting.'

Amin and Thrift (1992) see regional clusters as 'Neo-Marshallian nodes in a global network'.

Since the late 1990s UK industrial policy has embraced the idea of clusters with unprecedented enthusiasm, and the DTI nationally (Sainsbury, 1999) and the Welsh Development Agency (WDA), Scottish Enterprise and the new English regional development agencies all put great strategic emphasis on the encouragement of clusters. In Germany and the USA, too, there is strong support for growing clusters in emerging high-technology sectors. This regional emphasis goes hand in hand with other policies that continue to address national supply side factors, in systems for education, training, research and development finance, while the international dimension is addressed through policies on free trade, protection, competition, regulation and encouragement to firms to export.

Support for high-technology industry is thus provided at a number of levels – regional, national and international. However, the extent to which firms operate in these three arenas, and how relevant government action is for the needs and behaviour of firms regionally, nationally and internationally is open to question. The present focus on clusters at the regional level may be at odds with global patterns of trade and networking for innovation, and there may well be important differences between firms according to size, age and sector, which public policy is not sensitive to. The relevance and impact of policy for new high-technology firms needs to be measured, therefore, against the innovation processes and experiences of firms themselves. The aim of this report is precisely this: to evaluate policy in the light of firms' own innovation processes.

1.2 Regional development versus global networking in Wales and Thuringia

This study is concerned with innovation in Germany and the UK in a particular industry – opto-electronics – which has a highly global character but is also characterised by concentrations of firms in regional clusters.

A previous study into opto-electronics in six regions of the UK, Germany and the USA confirmed the high degree of global activity but also revealed significant differences in the development of these regions as clusters (Hendry et al., 1999; Hendry et al., 2000). Two regions, in particular, stood in marked contrast. The area of **Thuringia** around Jena can lay claim to being the most developed as a classic industrial district. **Wales**, on the other hand, is in many respects its antithesis. While Thuringian firms are strongly focused on local suppliers and collaborators, and are surrounded by a network of local research centres, opto-electronics firms in Wales look outside the region (internationally as well as nationally) for their customers, suppliers and collaborators

Notwithstanding these differences, Wales and Thuringia have regional agencies that have been pursuing active policies for regional development against a background of economic decline. However, their policies towards opto-electronics, which each has identified for special attention, have had a rather different focus. Whereas Thuringia has concentrated on technology transfer and enterprise development, the WDA has promoted international marketing and global alliances for local opto-electronics firms, while seeking to raise the industry's technology base.

As a result the contrasting experiences and policy emphases of these two regions provide an opportunity to compare the relevance, appropriateness and impact of government policies towards a high-technology industry (opto-electronics) in the light of the industry's global character and its distinctive patterns of local evolution. The question is whether a regional policy based on linking firms into the global economy (Wales) is more viable, appropriate and sustainable than the development of a regional technology system (Thuringia), and what lessons for innovation can be derived from the experiences of firms under these two regimes.

The study reported on here had two principal objectives:

1. To assess the relevance and impact of contrasting regional development policies towards the opto-electronics industry in two regions of Germany and the UK; specifically, to investigate whether globalisation is making local systems of innovation less relevant
2. To derive lessons for regional policy implementation and management from the success of these two regions in (a) stimulating technology transfer and innovation and (b) linking firms to global systems of innovation and markets.

However, the relevance and impact of policy needs to be measured against the innovation processes and experiences of firms that are intended to be the beneficiaries of policy. In studying these processes in the two regions, a third objective was therefore:

3. To highlight key issues in the innovation process among opto-electronics firms in Germany and the UK and to develop lessons for best practice.

1.3 Research design and methodology

The research for this report was carried out in three stages between November 1998 and September 1999:

- **Stage 1** involved interviews with officials in each region and in central government, and a study of relevant documents and records. The purpose of this was to establish in detail the character of national and regional policies towards opto-electronics in Wales and Thuringia and the means being employed to implement them.
- **Stage 2** reviewed the characteristics of the opto-electronics sector in each region, in order to build up a picture of its strengths and weaknesses. In the case of Wales this meant reviewing our existing case material on 18 firms and other more recent

work. In the case of Thuringia it meant developing our knowledge of companies and their networks through a wider range of interviews and documentary sources.

- **Stage 3** involved detailed case studies of firms in each region (six in Wales, eight in Thuringia), all of whom were known to be active innovators (for details of the approach see Appendix A). The cases focused on companies' approaches to innovation as the basis for assessing the relevance of government policy, and sought managers' views on the relevance and impact of forms of government support.

Overall, therefore, this study has wide-ranging implications for regional policy, for industrial clusters in high-technology industries and for innovation generally.

2 Opto-electronics

2.1 Opto-electronics technology and products

Opto-electronics (also called ‘photonics’) is one of a new breed of science-based technologies which involves manipulating materials at the atomic level (Kaounides, 1995). It brings together two basic technologies (optics and electronics) in a process of ‘technology fusion’ (Dubarle and Verie, 1993). It has been defined by the UK government’s former Advisory Council on Science and Technology (ACOST) as ‘the integration of optical and electronic techniques in the acquisition, processing, communication, storage, and display of information’ (ACOST, 1988).

The industry operates at three levels (Miyazaki, 1995). The lowest level consists of generic technologies (fundamental materials-processing technologies) and the advanced materials they create. Then comes the key components level, where different materials combine to form components (or ‘devices’), with distinctive attributes. The third, top level is where components and devices come together from different technological streams to form products and systems with end user applications. Opto-electronics is pervasive in modern life, but as its role is primarily that of a technological enabler, product markets are rather fragmented (see Appendix B).

2.2 Opto-electronics in the UK and Germany

The growth of opto-electronics in the UK has been largely due to the impetus provided by the military and telecommunications markets, and the leadership of British Telecommunications (BT) and the Ministry of Defence (MoD) in fostering research and development in universities and private industry (ACOST, 1988). BT was one of the first companies in the world to install optical fibres in its network and the MoD instigated many new developments in night vision systems and liquid crystal displays.

At the same time the UK has seen considerable inward investment. For example, Nortel Networks took over STC and then made Paignton a world centre for its manufacture of opto-electronic components. Other examples are Hewlett Packard taking over the ex-BT facility at Ipswich when BT withdrew from direct manufacture, and the Corning-BICC joint venture to produce optical fibre on Deeside. Although inward investment has been mainly in manufacturing, there has also been significant investment in R&D. For example, Sharp set up an R&D centre at Oxford in flat panel display systems, and more recently Lucent have set up a centre at Ascot.

The opto-electronics industry in Germany, by contrast, stems predominantly from developments in the existing optical and precision engineering sectors, rather than from fundamental new developments in the electronics industry. Existing competences in optical and precision engineering were enhanced by the development of skills and knowledge in opto-electronics in large companies such as Zeiss and Siemens, as well as in the research institutes, especially the Fraunhofer and Max Planck institutes, universities and polytechnics (*Fachhochschulen*).

The evolution of the German opto-electronics industry can be seen at the component level by focusing on certain types of opto-electronic products – lasers, photovoltaics (solar cells), light-emitting diodes (LEDs), fibre-optics – and markets for these products. For example, a particular strength is in powerful lasers for precision engineering (industrial) applications. This grew out of the formation of many new research institutes in laser technology in the 1980s and 1990s. With 35 institutes at universities and polytechnics, six Fraunhofer institutes, three Max Planck institutes, one large research institute and 19 other research institutes active in the field of laser technology, Germany now boasts an extensive research infrastructure which covers nearly all parts of laser technology (Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF), 1995).

In both Germany and the UK there is a clear tendency for firms to become concentrated into certain localities. In Germany such clusters can be found at Göttingen, Dresden, Aachen, Stuttgart, Munich and Jena (UK Consortium for Photonics and Optics (UKCPO), 2000). In the UK clusters can be found in Central Scotland, East Anglia, Wales and in a broad band stretching from Oxford down to Southampton (Hendry and Brown, 1999). However, the extent to which these are true clusters comparable to Silicon Valley is open to question.

2.3 Opto-electronics in Wales and Thuringia

Wales attracted multinationals during the 1970s and 1980s, with regional development grants and other forms of assistance, and this included firms in the newly emerging opto-electronics industry. In addition, opto-electronics in Wales owes much to one company, Pilkington plc, especially in the extent to which the industry is now clustered around the small town of St Asaph in North Wales. In South Wales much of the opto-electronic activity owes its presence more directly to inward investment.

In 1957 Pilkington (primarily a manufacturer of glass for the construction and automotive industries) established a new division in North Wales, specialising in the production of high-quality ophthalmic glass (Barker, 1994). From this initial investment, augmented by a policy of diversification in the 1980s, Pilkington spawned a number of new enterprises in the emerging opto-electronics technologies. The result is a cluster of firms, some of which were formed as Pilkington employees left to set up on their own. As one of the largest local companies, Pilkington has exercised a good deal of influence over the years, with its chief executive playing a prominent role in promoting initiatives on behalf of the area. Although the company's role is muted in organising the local network of firms commercially, because its spin-offs are quite diverse, there remains a loose personal network of Pilkington people.

The degree of commercial and social integration of opto-electronics in Wales is overshadowed by Thuringia, with its long history as an industrial region focusing on automobiles, optics, mechanics and electronics. Geographically this was concentrated in the so called 'technology triangle', the district between Erfurt (with strengths in micro-electronics), Jena (in optics, opto-electronics, chemistry and manufacturing technology) and Ilmenau (with its technological university). A key factor has been the existence of Carl Zeiss in the region for more than 150 years. During the GDR period Carl Zeiss in Jena was formed as a *Kombinat*, an organisation that integrated research and development, production and social welfare in one company. Thus there were close relationships with research centres in universities and elsewhere, which functioned, in effect, as part of the company.

After the re-unification of Germany in 1990, the *Treuhand* (the agency set up to privatise the former state-owned businesses of East Germany) took over such institutions with the objective of transferring them into market-capable units. In the case of Carl Zeiss, this disintegration ended in two companies: Carl Zeiss Jena GmbH (which is a sort of daughter company of Zeiss Oberkochen in western Germany) and Jenoptik AG (in which all the remaining companies were integrated). The subsequent dismantling of the non-viable parts of the business inherited by Jenoptik and its restructuring was then carried out by the new management of the company.

Soon after the founding of Jenoptik the former prime minister of the state of Baden-Württemberg, Lothar Späth, took over the job of CEO in order to make it a profitable firm. The task confronting Lothar Späth was twofold. On the one hand, the region of Jena depended heavily on jobs provided by the *Kombinat*, and hence on Jenoptik; on the other hand, it was crucial to focus on the development of new products and markets. The difficulty was that Jenoptik's former market in Eastern Europe had faded away; it did not have new products that could be successfully introduced into key markets; and it did not have a brand name that was known in the West. Späth resolved this by concentrating on its strong divisions, and divesting other activities into small and medium-sized enterprises (SMEs) that had the potential to develop into innovative, technology-oriented firms.

Alongside the changes in industry, Thuringia's institutions were purged and transformed. Many university staff were dismissed after re-unification because their departments were made redundant in the course of restructuring. Some of these departments were transformed into small specialist laboratories, and these now play an important part in the network of high-technology industries. Other individuals are now to be found as managers or technical staff in the new SMEs. The result is that some of the personal networks from the old system continue and play their part in networks that link the research centres and commercial businesses. The Thuringian situation is therefore now characterised by two overlapping networks of personal relationships: a native Thuringian one, and that imported with Lothar Späth. Together these offer the potential for a successful innovative climate, by being both locally focused and linked into the wider national scene.

In conclusion, Wales and Thuringia have some features in common and, indeed, are quite comparable in terms of size, but opto-electronics in Thuringia is more concentrated, both in the distribution of the industry and the networks among its people. Table 1 shows the overall profile of the two regions. Note that while the figures suggest that Wales has a denser educational and research infrastructure, this is not a true picture because it is more diverse and less focused on opto-electronics.

Table 1
Demographic and institutional comparison of Thuringia and Wales

	Thuringia		Wales	
Area (km²)	16,171		20,779	
Population	2,462,836 (1998 figure)		2,926,900 (1997 figure)	
Major towns	Erfurt – 204,000 Gera – 118,000 Jena – 99,000		Nearly 75 per cent of population lives within 60 miles of Cardiff	
Employment	972,100 (1998 figure)		987,363 (1997 figure)	
		%		%
	Government	17.4	Primary	3.7
	Manufacturing	19.7	Manufacturing	21.7
	Construction	15.8	Services	69.9
	Commerce	11.9	Other	4.7
	Services	18.8		
	Other	16.4	GDP	%
			Primary	3.3
			Manufacturing	29.3
			Energy/construction	8.4
			Private services	36.6
			Public services	22.4
Education and research institutions in all sectors with examples of key centres in brackets	Heavy concentration in Erfurt and Jena		Mainly in South Wales but more distributed than Thuringia	
College or university	5 (FSU Jena)		15 (Cardiff, Swansea, Aberystwyth, Bangor)	
Non-academic research facility	9 (Fraunhofer, Max Planck)		35 ‘centres of expertise’, all but one or two in university departments	
Polytechnic	3 (Fachhochschule Jena)		28 institutions (11 FE colleges, 9 tertiary colleges)	
Business-oriented research institution	20 (CIS, MAZet)			
Technology and initiative centre	10 (TIP Jena)		14 science park or incubator centres	
Transfer centre	10 (THATI)		16 industrial liaison offices mainly in universities	

Source: http://www.thueringen.de/index.html, http://www.stift-thueringen.de/en/index.htm, http://www.invest-in-wales.com/, http://www.wda.co.uk/

3 Innovation in the modern world

In this chapter we set out a framework for thinking about innovation, as the basis for analysing the case examples. This emphasises two things:

1. Innovation as an interactive sequential networking process
2. The role of tacit and explicit knowledge in innovation.

The first provides the basic framework, the second a theory of knowledge creation. A third contribution, by Fumio Kodama, highlights three key management practices which enable firms to successfully navigate the process of innovation. These are therefore our three building blocks.

3.1 Innovation as an interactive sequential networking process

The definition of technological innovation adopted here is that proposed by Freeman, who describes innovation as a process which includes

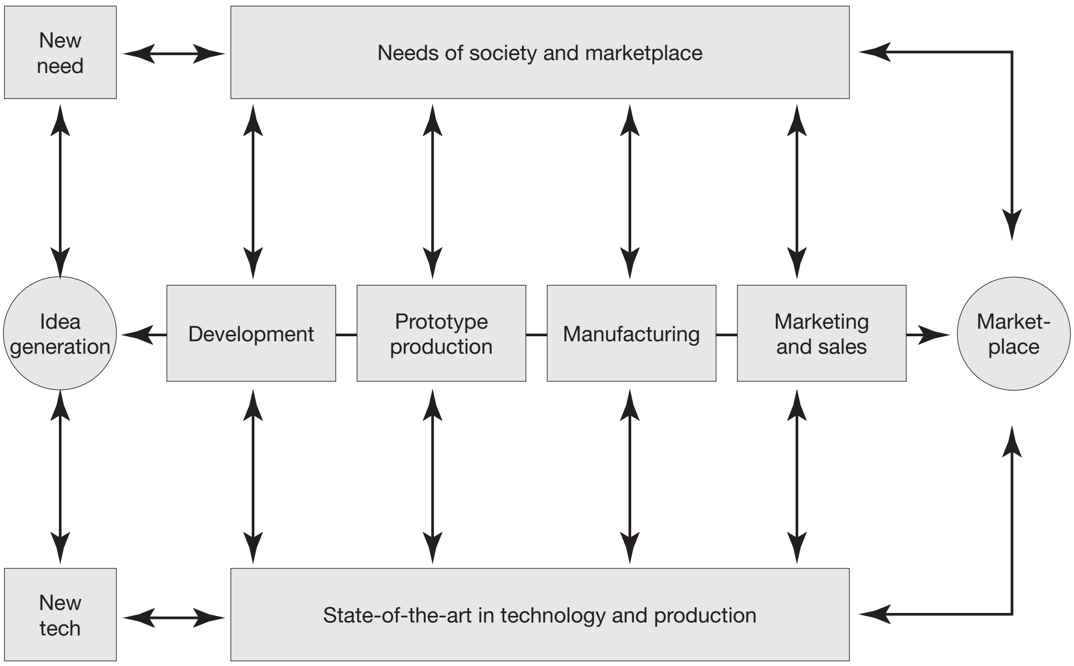
> 'The technical, design, manufacturing, management and commercial activities involved in the marketing of a new (or improved) product or the first use of a new (or improved) manufacturing process or equipment.'
>
> (Freeman, 1974)

As this suggests, innovation is not limited to technological advances. Successful commercialisation of technology involves organisational, management, production and commercial changes.

Early linear technology-push and market need-pull models of innovation are now regarded as oversimplified and extreme examples of a more general process of coupling between science, technology and the marketplace. A more accurate model of the innovation process is provided by Rothwell (1992). This 'interactive model' (Figure 1) illustrates that the underlying linear process is overlaid by numerous feedback loops and other network connections.

Rothwell characterises a fourth generation model as a parallel process with simultaneous activity in R&D, prototyping and manufacturing. In a fifth generation 'systems integration and networking' model, Rothwell sees an 'electronification' of innovation, resulting from the use of expert systems and information technology. The innovation process is becoming more efficient, faster and more flexible, through the use of electronic toolkits. At the same time its complexity has increased as more actors get involved, and innovation now has to be seen as a multi-institutional networking process.

Figure 1
Rothwell's interactive model of the innovation process



Source: Rothwell (1992)

Many commentators argue that these networks have a localised character. Some would say that spatial clustering of firms and related institutions has always been an important factor in economic development (Scott, 1998). Although modern transportation and communication technologies might be thought to counter this localising tendency and 'eliminate geography', Scott argues that, on the contrary, the trend is towards more finely grained patterns of geographic differentiation and inter-regional trade. This view of networking thus integrates the perspectives of localised regional clustering and globalisation.

3.2 Tacit and explicit knowledge in the innovation process

A second perspective on strategic approaches to innovation is provided by Nonaka and Takeuchi (1995). Their focus is more on the way in which each stage of the innovation process is affected by the nature of the knowledge deployed. Nonaka defines two kinds of knowledge – explicit and tacit (Nonaka, 1994). Explicit knowledge can be expressed as data that can be exchanged and shared over great distances, using information and communication technologies. Tacit knowledge, on the other hand, is not easily visible and expressible, but highly personal, making it difficult to communicate to others, unless they are sharing the same physical space, thought processes, values and assumptions. Tacit knowledge is therefore often geographically localised, which implies that any dependency on tacit knowledge for innovation requires close proximity of the participants and everyday face-to-face exchanges.

Nonaka sees innovation as a spiralling process of interaction between explicit and tacit knowledge, as a new product idea moves through research, prototype, manufacture and market introduction. 'Fuzzy' tacit notions, articulated and discussed within a work group, crystallise into a product concept that is then researched and evaluated explicitly. This stabilises the product concept and forms a platform for further development as it enters the manufacturing and marketing stages. The cycle turns again as feedback is internalised, evaluated and re-articulated as enhancements and new developments.

3.3 Management practices in innovation

The third area of concern is the practical one of how companies manage the innovation process in relation to external sources of knowledge. As the pace of technological innovation quickens, companies find it harder to keep up with discoveries that increasingly come from outside the native industrial setting. Consequently companies need to acquire knowledge and skills in technologies that are foreign to them.

There are two broad strategic responses to this situation, depending on the nature of the discovery and how it relates to a company's existing expertise. The more dramatic one is for a company to invest in research and development in the expectation that new discoveries will ultimately replace existing technologies and processes. A more pragmatic strategy would be to focus on combining the company's knowledge of existing technologies with emerging new discoveries to form 'hybrid innovations'.

The former is a strategy of radical technology change, requiring considerable investment in basic research. It is risky and often does not have a clear idea at the outset of the wider market opportunities. Hybrid innovation, on the other hand, is more cautious and incremental in its approach. At each step forward product performance can be checked for compliance and 'fit' with existing technology and the expectations of the market.

At its present stage of development, with many of the fundamental technologies established, we might expect the opto-electronics industry to be more likely to adopt the hybrid innovation approach. Kodama (1992) advocates three management principles that can help a company implement an innovation strategy:

1. Let the market drive the research and development process, not the other way around, through a process called 'demand articulation'. This is a process of transferring loosely defined ideas about future market requirements into firm product concepts.
2. Develop a strong intelligence-gathering capability both as a defence mechanism and as a source of new ideas.
3. Take part in collaborative research and development, especially initiatives that involve a firm looking outside its own industry.

These three principles, which are especially relevant to opto-electronics and the hybrid innovation process, provide the lens for analysing innovation in our case companies.

4 Company strategies for innovation

In this chapter we describe the approaches to innovation of our case companies in terms of the three key management processes defined above and compare the experiences of the Welsh and German firms.

4.1 The case companies and their innovations

Tables 2 and 3 summarise the key characteristics of the case companies in terms of products, markets, ownership, source of innovation and developments. Throughout we refer to all firms using initials.

The Welsh firms are generally older, ranging in age from eight to 33 years at the time they were visited, with a median age of 18.5 years. WF was originally formed as a breakaway from WD, but while both produce imaging systems for the military market, WF has a stronger commercial line. Similarly, WC was spun out from WB, but while both are in markets related to optical discs, one makes the discs and the other the manufacturing equipment. The other two firms are in industrial markets. All the Welsh firms have a strong international orientation, four having high levels of exports. Even more conspicuous is the fact that three are part of multinational corporations (MNCs), while one is a lead partner in a recent merger with a US company. The other two are privately owned, although one of these was itself for a time part of a larger MNC.

All the firms were selected because they were known innovators. Four of the Welsh firms have classic origins in that they were established to develop innovations out of university research (WA, WE) or out of another company (WC, WF). But there was a significant stimulus even here in at least three cases from collaboration with another company outside the region. Since then, collaboration with customers, suppliers, parent group or research centres (universities and governmental) has become increasingly important for new product development. Close collaboration with customers is a particular feature.

The German firms are noticeably younger, ranging in age from four to nine years and a median age of seven years. However, this is slightly misleading, since TD and TH were originally part of the Carl Zeiss *Kombinat*, and were created as substantial companies in the restructuring after 1991. The disappearance of the old economic system was followed by new ownership structures and new companies emerging, partly as spin-offs from previous businesses and partly as new firms. The majority, though, are genuine new start-ups. Their target markets are rather more diverse than those of the Welsh firms, with an industrial and scientific bias.

Being new, most are also SMEs, reflecting the structure of German industry in general. Thus, four of the eight have around 50 employees or fewer, compared with only one firm of this size in the Welsh sample. Three are SMEs spun out from Carl Zeiss, one is an SME start-up from a university and one is an SME owned by a consortium of other SMEs.

Table 2
Case companies in Wales

Company (start year/ employees)	Position in three-level model and markets	Ownership	Source of innovation	Developments
WA (1987/200)	Generic technologies Epitaxial wafers Almost 100% sales to major opto-electronics component manufacturers outside UK	Initially private, now merged with US company and quoted on EASDAQ Company started operations in Wales attracted by inward investment support	Company was started to commercialise production of epitaxial wafers based on experience in university and industrial research	Extensive collaboration with research institutions both local and remote Collaboration with key (German) supplier of manufacturing equipment
WB (1971/150)	Systems Production systems for making 'master discs' in optical disc industry	Private after unsuccessful period of venture capital support Company relocated to Wales for private reasons	Founders built on previous experience making vinyl discs Major breakthroughs into optical discs came after collaborative experience with multinational corporations (MNCs) in media industry	Current generation equipment based on use of lasers Now exploring product enhancement options based on electron beams.
WC (1991/370)	Components Manufacture of pre-recorded optical discs	Spin-off from WB originally Now part of UK-based MNC with extensive interests in media products	Product improvement to enhance appearance of disc and provide greater copyright security resulted from approach by non-local company specialising in holographics	Product improvement incorporated in new process equipment as part of factory expansion plans
WD (1966/400)	Key optical components and systems for military markets Image enhancement (night-sight) and display systems are core technologies	Joint venture between UK glass manufacturer and French military hardware supplier Originally part of UK company	Optics expertise built up in military applications from greenfield start in Wales in 1966 Major new product innovation derived from holographic research in parent UK company Manufacturing expertise developed in-house	Potential for holographic idea to be exploited in commercial vehicles, but will require modifications and cost reductions Group expansion opens up new market opportunities but concerns expressed about source of research inputs
WE (1986/25)	Systems based on use of ruby and CO_2 lasers Industrial markets for sensing and marking applications	Private company status restored after unsuccessful merger with US company Original start-up created by academic from local university, who is still actively involved	Idea for product with mass market potential in cosmetic surgery field came out of university research Not a commercial success, mainly to do with flawed marketing arrangements	Company is now going back towards the role of a commercial R&D organisation Looking at opportunities for exploiting local university research as customised solutions for industrial clients
WF (1982/100)	Systems for optical imaging and delivery Similar to WD but with a much stronger commercial bias	Originally a spin-off from WD After several ownership episodes is now part of a MNC Close connections to a sister company in same group with expertise in thin film coatings, based outside Wales	Original expertise derived from WD, but now extended by inputs from sister company in group Major new product development being driven by key customer	Inclusion in large MNC now offers this company the chance to become the specialist centre for precision optics within the group Some functions on one other site have already been transferred to Wales

Table 3
Case companies in Thuringia

Company (start year/ employees)	Position in three-level model and markets	Ownership	Source of innovation	Developments
TA (1990/180)	Analytical instruments (60%) and components (40%) for environment, medical and agricultural markets	Private with substantial part (25%) owned by Jenoptik	History of expertise in instrumentation in Carl Zeiss now moderated by key customers	Extensive research collaboration with research institutions (not necessarily local) Expanding into micro- and bio-measurement systems
TB (1993/42)	Prototype systems for industrial and research markets	Consortium of 30 regional SMEs	Research and development centre mainly in sensors and microsystems	Initially dependent on local markets but now looking to expand outside region with own products
TC (1991/140)	Systems for positioning and security applications	Management buyout from Carl Zeiss	One product idea with worldwide potential came from medical physician Local customers initiate customised product ideas	Exploit medical product globally Expand customer base for industrial and meteorological products outside region
TD (1995/350)	One-third each generic technologies, components and systems	Jenoptik	Diverse set of technologies built on optics and lasers developed in Carl Zeiss era for sensing and measuring applications in industrial and military markets	Strategic intent to move up the three-level model and concentrate on products and systems Use made of local research infrastructure but 60% international sales means a greater focus on extra-regional sources of innovation
TE (1993/38)	Components (lasers)	Management buyout from Carl Zeiss Company HQ, sales and service in Munich Jena is manufacturing location	Company started as distribution outlet (in Munich), which then purchased gas laser facility in Carl Zeiss	Traditional strength in gas lasers now being extended into newer types of laser, partly by acquisition
TF (1990/14)	Components (optical elements and coatings) for industrial and scientific markets	Private; founder was academic at FSU Jena	Founder's expertise in optics	Initially dependent on local markets (still 50%) but now expanding outside region Part of local network of research experience
TG (1992/55)	Products and systems Solutions based on integrated circuits with optical and electronic elements for sensing and signal processing applications Industrial and IT markets	Ownership split between Carl Zeiss, Jenoptik, two major customers, and management 'Business-oriented research institution'	Spin-off unit from Carl Zeiss Carl Zeiss and Jenoptik still important customers	50% of business is local, but now looking outside region and Germany Local research collaboration with Fraunhofer Institute
TH (1992/500)	Key components Application-specific integrated circuits (ASICs) for industrial applications	Ownership changed two times after *Treuhand* Now part of Belgian MNC	Company goes back to 1937 as part of Telefunken Major integrated circuits centre (with fabrication facilities) in GDR	Specialist supplier of integrated circuits to 'mixed signal (analogue to digital and HF) markets' Extensive research collaboration intra- and extra-regional

In contrast to the Welsh firms, only one is part of a larger MNC. However, Carl Zeiss and/or Jenoptik retain a significant controlling interest in a number of these small firms, and therefore a strong network of financial and technological relationships is providing a degree of support and protection to these smaller firms. This is reflected in the fact that four of these derived their technology and initial product ideas from Carl Zeiss, while TD and TH took over established products from Carl Zeiss. TB is similarly embedded, in a network of SMEs, as a research centre developing prototypes. Only TF involves a product idea that has come directly out of a university.

While their origins and early stage of development mean that most have a strong dependency on local customers and research, there is nevertheless considerable pressure to develop research links and customers outside the region, driven by a clear recognition that local markets are not enough to sustain specialist products. Export sales are as yet undeveloped, though. This is not true of TD and TH, which have more extensive links outside Thuringia, although they too make considerable use of local sources for innovation.

4.2 Demand articulation

'Demand articulation' is the process of transferring loosely defined ideas about future market requirements into viable product concepts, through extensive dialogue with key customers. In many markets developing a product means working with potential customers in order to understand user needs more precisely. In opto-electronics this process necessarily has a strong technological component, since products have to work in conjunction with other components and systems. Achieving precise functional properties therefore depends extensively on close interaction between producers, suppliers and customers. The continuation of links, once formed, can also help with second- and third-generation product development.

WF illustrates this through its development of head-up displays:

> 'For years we have supplied optics for head-up displays for military aircraft, where our biggest customer has been [a UK defence systems manufacturer]. We know them well, as we have worked on other programmes with them. In this case they identified a market opportunity and we convinced them that we were the people to use for the optics. Now we have a product in the marketplace, and a vigorous programme to get the cost down. Phase 1 of the development was to demonstrate that new materials could give acceptable performance. Phase 2 will be to improve on the design to bring more cost out, and investigate the use of new coatings, which is a whole new ball game. It will also look at the use of plastics in other areas. Within two years we might be incorporating new material elements into the current production model.' [WF]

More commonly, working with customers on a regular basis generates incremental product improvements and a stable revenue flow. Thus, WA follows a strategy of 'product enhancement' through working closely with its customers overseas. Since markets are competitive, the choice of who to work with is crucial in terms of staying at the leading edge and having designs that take account of the latest materials and key components.

Close relationships with large international companies are a feature of the Welsh opto-electronics industry. To some extent this is a consequence of the fact that the industry operates at the components (or generic materials) level, and as there are no local 'system integrators' (Hendry et al., 1999), they have to look outside the area for their markets. An additional factor is that the end markets served by Wales are quite diverse (military, industrial, consumer) with no particular local emphasis.

In Thuringia, by contrast, the dominant markets are industrial and scientific (for sensing, measuring and machining applications). Customers are located primarily in Germany (with a sizeable proportion in Thuringia), although some companies are now attempting to expand into exports. There is little evidence of significant relationships with major customers acting as interpreters of market requirements and providing access to global markets. Although Jenoptik might have been expected to play this role and/or act as a 'system integrator', it appears instead to have concentrated on originating technology and promoting new start-ups, rather than acting as a customer. This may be changing, though, as Jenoptik develops its strategy of acquiring companies outside Thuringia and building its own international reputation (see Chapter 4.4).

Product development in Thuringia appears to be heavily driven by technology, with companies then looking for market opportunities. A typical response to the question 'what are the origins of your product ideas?' is that they come from inside the company, from a local technical research centre or finally from customers (in the plural). Further evidence comes in companies' marketing activities, where much of their activity outside Germany is through distributors, agents, trade fairs and the Internet. This suggests a strategy of finding markets for products (a 'sales' approach), rather than collaborating with global organisations to get access to emerging markets.

An illustration of the basic stance of Thuringian companies is the example of TB and TG, owned, respectively, by a consortium of local SMEs and a group of companies that include Jenoptik and Carl Zeiss. TB and TG function as R&D consultancies, developing prototypes from ideas coming out of their parent organisations (but sometimes also from other sources), which are returned to them when they have been turned into viable products, or pushed out for others to exploit. The driving force is thus from the technology rather than from the market, but once products are established in the local market, TB and TG plan to grow these nationally and then internationally.

The contrast between Wales and Thuringia, in the extent to which demand articulation contributes to product definition, is reflected in attitudes to protecting intellectual property rights (IPR) through the patenting system. Generally speaking, the Welsh case companies are aware of the patenting system but doubt its value and are somewhat backward in applying for patents. A good part of the reason is that products are developed in co-operation with clients so that the specification and problem definition are considered the customer's intellectual property, whereas the design (and the production know-how) belongs to the supplier company.

In Thuringia, by contrast, use of patents is quite widespread. Six out of the eight case companies confirm that they use a variety of formal means to secure intellectual property rights, including patents, trademarks and licences. This is a strong feature of the innovation system generally in Germany (Paci and Usai, 2000). In Thuringia this is institutionalised in the official patent documentation office for the state of Thuringia, PATON, which is a part of the Technical University of Ilmenau.

4.3 Intelligence-gathering

Product development needs to be guided by a company's knowledge of longer-range technology trends and emerging market issues. While demand articulation is the process by which companies identify market opportunities, 'intelligence gathering' (Kodama, 1992) is how they keep up with technological developments. Companies need to be active in relation to both markets and technology. Ultimately they have to be able to connect the two. Thus it is critical to establish a connection between an envisioned technology – the kind of performance advance it is believed capable of delivering – and a sense of how such a performance advance might impact on the market (Sheasley, 1999).

There are some notable examples of case companies maintaining a strong 'technology watch' (Drilhon and Estime, 1998). WA, which is probably closest to basic science in its product and therefore has the greatest incentive to keep up with new discoveries, has been involved in a long succession of collaborative ventures. In many cases they have not have been particularly active, and the projects may not even have delivered much of tangible value to them. But their objective has been less to develop a particular product or process than to keep up with developments in their field and 'raise our technology base'.

In the past UK and Welsh firms in certain markets, such as defence, could rely on government-funded agencies to conduct research and give direction to company R&D by awarding contracts for government defence procurement. WD, in particular, had strong links with the UK's Defence Evaluation Research Agency (DERA). This relationship has now changed:

> 'The most important external research laboratory has been DERA, much more so than the universities. DERA is more applied, it has a remit for defence issues, it is aligned with operational units – whereas the universities are more interested in pure technical capability. Ten years ago we worked with DERA on probably just about everything, because this gave the company a very close link into the Ministry of Defence's thinking. What happens now is that alliances with DERA tend to be restricted to materials research and DERA is beginning to commission research that involves both universities and companies.' [WD]

At the same time as external sources of technology have become less freely available, UK companies have refocused their investment in R&D on research that has more chance of immediate commercial application. This affects medium-sized companies such as WD:

> 'We will have to link in with other sources of information about products, components and materials development, and take these before others have got them, rather than wait for everybody to reach the same level of knowledge. First, we have to maintain a watching brief on developments – 'technology scanning' the right centres and looking in the right places (usually the physics department of universities) – and when something starts to look interesting, develop a dialogue with the institution to build up the relationship.' [WD]

However, whether firms can do this successfully depends on how they organise their own R&D. A key feature in the Welsh companies is that their R&D is organised on a project basis. In many instances, rather than being in one department, R&D is actually spread around the company and so encourages project-based working. This ensures that tacit information is more readily propagated around the company and develops 'absorptive capacity' (Cohen and Levinthal, 1990). WD, for example, has a formal R&D department with a budget at around 5 per cent of turnover, but a more realistic estimate of the full development budget is nearer 18 percent. Similarly, WA 'is doing research almost daily, as new capabilities are announced and customer requirements get more demanding'. In other words, R&D is embedded in continuing, project-based product development.

The same pattern is found in the Thuringian firms, which report R&D expenditures as a percentage of turnover ranging from 5 per cent to 50 per cent (with one company claiming a figure of 80 per cent). Thuringian companies make more use of external sources of R&D. All eight case organisations report some form of external R&D collaboration (although in two cases this is described as 'minimal'). The norm appears to be around 20 per cent of the research input coming from external sources. The most common partner is a technical institution or university, often (but not exclusively) one that is local. In this, they have the advantage of being able to draw on readily available local centres of technological expertise:

> 'Collaboration with research institutes is usually done on a project basis, with regular reviews at senior management level in the company and at symposiums with universities. There is a constant exchange of information between research institutes, universities and companies, who are all considered to be important sources of new product ideas. We then have what we call a 'reference customer' who will get an early prototype version of a product to be tested and provide us with feedback. Universities, research laboratories and the like are invited to discussion forums about products going through this process and this enables the company to respond immediately to potential problems.' [TA]

Welsh companies also collaborate with external sources of R&D, but only in one or two cases is this with a local technical institution. More commonly it is with a customer or a consortium of companies in a government-supported project. The inference from this is that intelligence-gathering in Thuringian companies is targeted at technological rather than market developments, whereas Welsh companies have been able, through their collaborative links with advanced customers, to get closer to emerging market requirements.

All of this may relate to the basic conception most of the Welsh firms have of themselves. As innovative firms they clearly take pride in their R&D capability and regard their core competence as being able to translate scientific ideas in optics and electronics into commercially viable products. In other words, there is an emphasis on design and development rather than on research. They are 'engineering' companies, therefore, and while this is a valuable strength, which has often been regarded as a weakness in UK innovation, it implies a focus on the immediate picture.

The Thuringian companies also emphasise their design capability. In addition, among the Thuringian sample are two organisations – TB and TG – which function as research and development consultancies (referred to as 'business-oriented research institutions'). These develop prototypes according to a design brief and then license them as technology for others to manufacture, or they manufacture the product themselves, or they create some form of spin-out.

4.4 Collaborative research and development

Kodama puts particular emphasis on collaborative R&D that leads to technologies from different industries coming together. The emergent character of markets in opto-electronics means a company may not have all the necessary knowledge and skills. It also reinforces the relevance of access to complementary competencies to facilitate the introduction of a product to the market. We consider collaborative R&D in terms of relationships between firms, and collaborations with university and other research centres.

Our findings in Wales suggest the critical importance of collaborations with other firms, but these have primarily involved vertical value chain transactions with companies outside the region. These include collaborative development of improved products or processes with major customers, as well as outsourcing complementary systems or materials from suppliers. There is relatively little horizontal collaboration among firms to create shared production systems or develop generic technology.

The case of WB highlights the role of the customer in commissioning product development:

> 'The relationship with [a media company] was crucial to us. They were not previously a customer before this collaborative development started. They had already changed suppliers twice [and were looking for a more reliable supplier who could do what they wanted]. The initial approach was made to us at a trade exhibition, where they came onto the stand and asked if we would be interested in developing mastering equipment for an experimental new recording format, which eventually became an international standard. After many months of collaborative effort, which involved sending prototype samples of master discs to the USA for testing, the new equipment was accepted by them.' [WB]

In Thuringia the picture of limited collaboration among small firms, and the dominant role played by collaborations within the supply chain, is very much the same, the difference being the greater likelihood of collaboration locally. A significant difference, though, is the way much of the collaborative activity around Jena in opto-electronics is dominated by Jenoptik and (to a lesser extent) Carl Zeiss. Undoubtedly the personal networks created in Carl Zeiss Jena within the GDR have become a solid foundation for collaboration.

Jenoptik has been influential in one other crucial aspect. In the early 1990s its R&D teams concentrated on a range of high-technology products, with the aim of competing in global markets. However, selling critical component technology 'made in Jena' proved difficult outside Germany, with international electronics companies reluctant to buy from a company without a proven track record. As a result Jenoptik embarked on a strategy of acquiring companies or founding joint ventures in Western Germany with recognised names in fields related to Jenoptik's products (Blau, 1999; Woodruff, 1998). At the same time Jenoptik pursued a policy of encouraging the creation of spin-off companies and then forming co-operative alliances with these firms and the local technological infrastructure. A consequence of this is that just 20 per cent of the company's 8,400-strong own workforce is now in eastern Germany, and the company now resembles a diversified organisation with 'distributed competence' (Granstrand et al., 1997), combined with a hinterland of technological and scientific expertise. As well as being the core of the regional innovation system, Jenoptik is therefore also creating a network of broader geographical links.

In one such local collaboration TD and a partner we call TDISPLAY are working together to develop a new projection display system to be based on lasers. TD and TDISPLAY are collaborating to design such a system based on the development of a red-green-blue (RGB) laser to commercial production levels. Under the terms of their formal agreement TD will develop the laser technology and TDISPLAY will handle overall design and systems integration. An indication of the growing internationalisation of the opto-electronics industry in Thuringia, and of Jenoptik's role in this, is that although TDISPLAY is located in Thuringia (where it was founded), it is now a joint venture owned by two major German companies, one of whom will do the manufacturing outside Thuringia.

Although Kodama restricts his comments to inter-industry collaboration on research and development, an important part of the innovation process involves collaborations with research institutions. In the UK this largely means university centres, although the government research agency DERA has played a significant role in the defence sector. In Germany, with its extensive range of university and research centres, there is considerably more choice of partner, but questions are being asked about the role of the education and research sector in stimulating developments in new technologies.

The UK has a disadvantage compared with Germany in the number of application-orientated research institutions. In Wales this is particularly acute, as there are none at all, other than centres of excellence in the universities, and this connection is itself at an early stage of development. Of necessity, then, if Welsh companies want to engage with research institutions, it is likely to be outside the region. However, even these contacts are limited, with just two other Welsh companies (in addition to WE) having had significant research links with universities outside Wales.

A good example is WA, which in one case was interested in getting feedback on how well a particular variety of opto-electronic wafer was performing. By joining a relevant ESPRIT project, the company was able to get much faster turnaround on performance data and this enabled it to accelerate development. The project effectively compared WA wafers with other suppliers' on certain characteristics, and as these comparisons were then in the public domain WA was able to use the results to publicise its capability in the field.

The strength of the German system of institutional research and development is well known. It broadly takes three forms:

1. Pure basic research in the universities, as well as in the universities of applied sciences (*Fachhochschulen*) as an adjunct to teaching
2. A greater amount of basic research (with intended commercial application) in the Max Planck institutes
3. Applied research carried out by institutions such as the Fraunhofer Institute.

Formal collaborative research in Germany is therefore more likely to be found between industrial firms and intermediate institutions, rather than between firms and universities, and there is also likely to be a significant amount of local state funding support for such activities. This is clearly seen in Thuringia, where the UKCPO report (2000) comments on collaboration between local firms and the Institute for Physical High Technology:

> 'Many of the research projects are collaborative, with about half of them involving local companies. They have relatively little involvement in EU projects. The State of Thuringia is very active in research funding. The most common mechanism is to support a group of interested organisations (one of the first of these was in micro-optical systems). Project research proposals are usually screened by such a group. The Institute is involved in such projects to the value of about DM 2 million per annum. The projects are intended to lead to a new or improved product for the collaborating companies'.

As Table 3 and the case examples show, all companies have been involved in some form of collaborative R&D project with one of more of these research centres. The company with the most extensive links into the research infrastructure in Thuringia is probably Jenoptik, which has a general contract with the university (FSU), the continuation of a tradition of funding at the university by Carl Zeiss going back over 100 years. Jenoptik companies are also interested in the work of the applied research organisations, where they offer funding either as a contract or as a grant, depending on circumstances.

TG provides an example of such collaboration between industry and academia. TG is developing and marketing a new kind of colour sensor that could rival CCD cameras for industrial control processes, where a comparatively low resolution is sufficient, but high speed is important. The new sensors are based on research at the Fraunhofer Institute for Applied Optics and Precision Engineering and being developed by TG (with others) in a project that is part of a BMBF scheme (Hill, 1999).

4.5 Summary

In summary, we review the case evidence from the three Kodama perspectives.

Clearly **demand articulation** is a feature of product development in the Welsh firms, which exchange tacit knowledge about market opportunities with a small number of international companies. In Thuringia, by contrast, there is less evidence of demand articulation forming part of the innovation process, except for the very largest firms. Rather, the Thuringian companies appear to take a 'bottom-up' approach, solving technical problems at the local level, often in partnership with commercial and academic research organisations, with the wider market opportunities to be developed later.

For the case companies in both regions **intelligence-gathering** is an important consideration, and they use a variety of means to keep up to date with developments in their respective fields. At the heart of this are R&D and design capabilities, and the way they connect into external networks. The evidence suggests that the Welsh companies may be more inclined to link into extra-regional agencies, such as large customers (or research institutions) with access to global markets, while companies in Thuringia take advantage of the local research network in a more informal face-to-face approach.

Finally, there is considerable evidence to suggest that Thuringian firms are using the local (and national) research infrastructure to do **collaborative research** on new product development to a much greater extent than appears to be the case in Wales. What is more in question (and this is also true of Wales) is the extent to which this involves technologies from other disciplines in a process of 'technology fusion' (as Kodama advocates).

5 Government support for opto-electronics and innovation

5.1 Introduction

In its classic form the linear model of innovation portrays scientific research as coming first, followed by engineering development and then manufacturing implementation. This perception has in the past allowed policymakers to believe that support for basic scientific research is the best way of stimulating innovation. The history of government policies on technology is littered with examples of investment in basic scientific research, in the expectation that inevitable success in the marketplace will follow. There are, indeed, many success stories, such as the Joint Opto-Electronics Research Sheme (JOERS) in the UK. However, it has long been recognised that the linear model of technological change is no longer an entirely reliable basis for technology policy. The shift away from **providing resource support** and towards **promoting learning through knowledge networks** forms the background to this chapter.

5.2 UK national policies

Technology policy in the UK, certainly in regard to opto-electronics, is dominated by three main institutions: the Department of Trade and Industry (DTI), the Engineering and Physical Science Research Council (EPSRC) and the Defence Evaluation Research Agency (DERA).

5.2.1 Department of Trade and Industry

Over the years the DTI has encompassed a wide range of policy responsibilities, but a key role nowadays is developing and co-ordinating government policy on science, engineering and technology, with the aim of encouraging innovation and the increased use of science and technology by business. The complete list of DTI activities is too long to review here, so we focus on a few initiatives that are relevant to opto-electronics.

The first involvement of the DTI in opto-electronics dates back to 1982, when the fibre-optics scheme was introduced to encourage product development and capital investment in fibre-optics and opto-electronics. Under the scheme over £50 million was spent on helping to set up optical fibre and related component manufacturing activities, mainly in single (large) company projects.

In 1984 the Joint Opto-Electronics Research Scheme (JOERS) was established. This was the DTI's first ever industry–university collaborative programme, and it supported technology developments in opto-electronics at the 'pre-competitive' stage. This was generally regarded as having been successful, but one consequence of the ACOST (1988) review of

JOERS was to change the focus of government support from pure research to the application of technology, and this was one of the factors behind the introduction of the LINK programme.

LINK has a very clear remit to support research projects with both academic and industry partners. The LINK Photonics programme, which started in 1989 as part of a broader pan-governmental collaborative R&D initiative, supports research into the integration of opto-electronic devices and techniques into systems with market potential. A specific condition of achieving support nowadays is that projects must involve one or more companies and one or more science-based partners.

More recently, a key policy that continues this theme of improving links between industry and academia but has much wider ambitions in terms of regional development, is the promotion of industrial clusters. A particular focus is the biotechnology industry, but the recommendations in the Sainsbury report (1999) have a more general application and are being picked up by the new regional development agencies as a policy objective. The origins of this thinking go back in part to the early days of science parks in the UK, which have, nevertheless, been criticised for not delivering in the same way as Silicon Valley has famously achieved for the US economy (Oakey, 1994).

Finally, an emerging theme in UK (and EU) policy is the creation of frameworks from which individual winning technologies ultimately emerge via market forces. The LINK programme is in this vein of thinking, with frameworks being defined broadly by technology. A much wider scheme is the Technology Foresight Programme (now called the Foresight Programme), which came out of the White Paper *Realising our Potential* (DTI, 1993). Its purpose is to forecast future research requirements in a number of industry sectors in a process involving panels and working parties composed of representatives from both industry and academia. The intention is that by bringing these communities closer together through networks, emerging opportunities in markets and technologies can be identified.

5.2.2 The Engineering and Physical Science Research Council (EPSRC)

The research councils in the UK were re-organised in 1994, also as a result of the White Paper (DTI, 1993). The EPSRC is now the UK research council responsible for funding academic research in engineering and the physical sciences. Traditionally this has been done entirely on the basis of approving funds for research proposed by individual university departments and evaluated by peer group committees. This has now changed somewhat, to become more concerned with industrial relevance.

One important historical development that may influence future thinking is past support for inter-disciplinary research centres. The Optoelectronics Research Centre (ORC) at Southampton, established in 1989, has proved to be a great success. Not only did it invent the erbium-doped fibre amplifier, which is now a standard component of backbone optical fibre networks, but it has been the genesis of a number of spin-off companies in the locality.

While this entails something like technology-push with greater industrial participation, another emerging theme is the recognition of the cross-disciplinary nature of opto-electronics (in particular) and the need for the EPSRC to take a more managed approach. Thus a recent EPSRC review (EPSRC, 2000) comments that ‘the diverse and interdisciplinary nature of Applied Optics research means that it has no single natural “home” in the present EPSRC structure’. One of the main recommendations of the review was therefore for a new managed programme, ‘Optics for Industry and Manufacturing’, to be set up with an emphasis on collaboration between groups and incorporation of a LINK programme. This materialised in summer 2000, with the launch of ‘Optical Systems for the Digital Age’.

5.2.3 Defence Evaluation Research Agency (DERA)

When DERA was created in 1991 (as DRA) from the amalgamation of the UK’s defence research establishments, it became the largest physics-based research organisation in Western Europe. It inherited an illustrious record for innovative research, most particularly for the ground-breaking work in liquid crystal displays and night sight detectors.

DERA is still active in opto-electronics, particularly display systems. It works on collaborative projects with industry, but these are biased more towards development than towards basic research, which is now regarded as the province of the universities. DERA’s job is primarily to procure systems and components for MoD requirements. It tries to take advantage of work done for the commercial market by using off-the-shelf components and devices in defence applications. DERA retains an interest in commercialising its own research and an important objective is to set up mechanisms for achieving this, but its prime role is to service MoD requirements.

5.3 German federal policies

The relevant ministry for technology policy in Germany is the Federal Ministry of Education, Science, Research and Technology (Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, BMBF). Other sponsors include the German Research Council (Deutsche Forschungsgemeinschaft, DFG), while the German Space Agency (Deutsches Zentrum für Luft- und Raumfahrt, DLR) channels funding from the BMBF into opto-electronics.

5.3.1 Federal Ministry of Education, Science, Research and Technology (BMBF)

The German technology infrastructure is uniquely characterised by the presence of a large number of (semi-)public research institutes. There is ample support from the BMBF for these institutes, but until recently there was no special programme focused on the opto-electronics sector as a whole. However, in July 2000 (after fieldwork for this study was completed) and after a 14-month strategy consultation process, the BMBF announced a DM 100 million programme: ‘Deutsche Agenda Optische Technologien für das 21. Jahrhundert’. This identifies actions in a wide range of technologies and markets, and in education and training.

This indicates a radical change in the situation from the early 1990s. Then the Organisation for Economic Co-operation and Development (OECD) noted that although ‘the Federal Government is supporting public and private institutes and firms’ R&D work in a number of areas related to photonics', the approach lacked the proactive and interventionist strategy which characterised the UK (Dubarle and Verie, 1993). It saw the German approach as rather fragmented. For example, the federal government initiative Laser 2000, managed by the Fraunhofer Institute for Applied Solid State Physics (IAF) in Freiburg, clearly concentrated on developing laser technology (Opto and Laser Europe (OLE), 1997; BMBF, 1995).

Now, as the recent UKCPO (2000) report notes, the German government accepts that the photon will be a major driver in the new millennium (in place of the electron), and that, as a matter of policy, 'we have to domesticate the photon'. Germany is therefore building on perceived strengths in traditional areas of optics and precision mechanics, and high power laser materials processing, where it is the clear market leader.

The microsystems technology programme 'Mikrosystemtechnik 2000+' is a good example of this new approach. It embraces systems in bio-technology, micro-technologies and nano-technology, and it operates through joint industrial projects, where the selection of projects is based not only on technical aspects but also considers market impact, exploitation strategies and business plans. Part of the programme is concerned with opto-electronics and all projects are collaborative (UKCPO, 2000).

More generally, German companies benefit from a number of support programmes funded by the federal government, some of which also function as transmitters for EU programmes.

The distinctive feature of these programmes is that they provide tangible resource support through all stages of the innovation process. They are also generously funded in comparison to equivalent UK schemes (UKCPO, 2000).

5.3.2 German Research Council (DFG)

DFG is the central public funding organisation for academic research in Germany. According to its statutes DFG's mandate is to serve science and the arts in all fields by supporting research projects carried out in universities and public research institutions in Germany, to promote co-operation between scientists, and to support links between German academic science and industry. In doing this, it gives special attention to the education and support of young scientists and scholars.

The DFG's system – which involves periodically elected and replaced honorary reviewers, a strict separation of reviewing and decision-making processes, and a unique private-law status in spite of government funding – has been accepted by the scientific community, industry and politics as an efficient way of promoting and funding research in Germany. DFG is thus broadly comparable to the EPSRC in the UK.

5.3.3 German Space Agency (DLR)

The role of the DLR is to undertake scientific research and develop technology for energy, aircraft technology, space technology and (very recently) transport. Much of this work is very closely related to opto-electronics. DLR operates large test facilities and performs various management services on behalf of the government. DLR sees itself as a modern research enterprise that focuses on integrating its own work with outputs from partners in research institutions and industry. It comprises 31 institutes in eight locations distributed throughout Germany.

Technology marketing and transfer (TM) is an activity of growing importance and is the remit of a specific department, which has offices at each of the individual DLR centres. TM offices undertake market studies to evaluate the potential of DLR technologies, transfer samples of new materials for evaluation by commercial enterprises and support start-ups by helping with business plans, acting as a mediator between DLR institutions, management consultants and venture capitalists. The UKCPO report (2000) comments on a number of examples of this policy working in Bavaria.

While the German system may be overly complex in terms of institutions and funding arrangements, it is more generously funded, covers the lifecycle of the innovation process more comprehensively, and shows more determination to reach out to smaller firms and engage them actively in innovation. The UK institutions, on the other hand, have a longer history of involvement with opto-electronics and are now making great efforts to embrace the innovation process more fully. In the next section we look more closely at developments at the regional level.

5.4 Regional policy and initiatives in Wales

The main institutions in Wales are the Welsh Office, the Welsh Development Agency (WDA), the network of Training and Enterprise Councils (TECs) and the 22 local councils.

5.4.1 The Welsh Office

Created in 1964 to take responsibility for public administration in Wales, the Welsh Office is now formally part of the Welsh Assembly. Most of its work is developing policy. Local authorities, non-departmental public bodies (such as the WDA) and TECS undertake many of the executive responsibilities.

A clear indication of current development strategies for technology in Wales is in the policy document *Pathway to Prosperity*, published in July 1998. The section on sectoral balance observes:

> 'Policy should not concentrate on the promotion of particular sectors, but instead should be focused on correcting or removing the market failures which prevent industries from achieving their full potential. In particular we see a role for policy in developing and maintaining mutually supporting networks which will help companies grow.'
>
> (Welsh Office, 1998)

5.4.2 Welsh Development Agency (WDA)

The WDA was created in 1976 to bring new companies and new industries into Wales, to create jobs and to stimulate entrepreneurship. Since its inception it has focused on two things – economic renewal and environmental improvement – both of which are important for a region that has historically specialised in coal and steel and faces problems arising from the contraction of these industries.

The two principal strategies adopted by the WDA for economic renewal are inward investment and business support services. Wales has a very successful record in attracting inward investment. But while traditional location attributes (such as low labour costs and good infrastructure) have given Wales a comparative advantage in the past, they are no longer sufficient to attract and retain high-quality investment. Wales (it is argued) needs to reinvent its location attractions to stay in the race for quality inward investment, and a number of bodies, not just the WDA, have a role to play in this process.

To enhance its technological standing, and its attractiveness to inward investors, the WDA is promoting ‘Global Link’ (a business development network for companies seeking overseas expansion) and has developed a Regional Technology Plan. This includes a flagship project to ‘support the opto-electronics industry in Wales to build technology and innovation alliances around the world through the Welsh Opto-electronics Forum’ (WDA, 1996). These two initiatives illustrate the idea of building networks and opening up local networks to global influences and opportunities.

With regard to business support services, one of the most important changes concerns delivery mechanisms. Taking the view that firms learn best from other firms, the WDA has recently put much emphasis on designing and brokering inter-firm networks. Initiatives cover three separate fields: supplier development, training consortia and technology support. The last of these includes the idea of technology clubs, one of which is the Welsh Opto-electronics Forum.

5.4.3 Welsh Opto-electronics Forum (WOF)

Formed in 1996, WOF has been an active force in bringing together a wide range of people interested in the development of opto-electronics in Wales. Sponsored initially by the WDA, it now has about 50 members, drawn from local companies and public research centres. It is a rather unique, regionally focused and sector-specific network, which is distinct from the trade associations in which firms normally participate and the professional associations for individuals. WOF has played an active role in supporting the initiatives of the WDA, especially ‘Global Link’ and the Regional Technology Plan.

5.4.4 Welsh Training and Enterprise Councils (TECs)

The first TECs in Wales were formed in 1990 as part of the general restructuring of training in the UK and were modelled on German and US experience. The TECs’ work is focused on ‘people development’, but the greatest part (around 90 per cent) of their budgets are directed at the unemployed. This division of resources is fairly typical of TECs across the UK. However, the TECs’ role in training is currently passing to the new Learning and Skills Councils, while regional agencies (in England) take over their role in economic development.

5.4.5 Local councils

Capital funding programmes in the UK are now commonly based on a competitive bidding approach. In Wales this is known as the ‘Capital Challenge’. Local authorities in Wales are asked to put forward one strategic capital programme each year for consideration by the Welsh Office. The criteria on which proposals are assessed are the need to generate jobs, encourage private sector investment, carry out environmental improvements that will lead to economic growth, and to involve all the community in the formulation, development and implementation of the programme. One of four successful bids in 1997 was the project ‘Bangor: City Of Learning’, to create an incubator centre linked through a fibre-optic network to local educational institutions. This project illustrates the way in which infrastructure support is now activated.

In summary, although the WDA and Welsh Office support development with financial resources, the emphasis is now on building networks for companies (along with research centres) to carry this forward. This resonates with the shift in certain areas of central government policy (for example, in the LINK scheme). However, while a number of notable university and other higher education research centres are doing work on opto-electronics, there is no emphasis on technological transfer via company spin-offs as the basis for innovation. Wales has few examples of firms in opto-electronics that have been formed out of university research and compares unfavourably with a number of other regions in this respect (Hendry et al., 1999). Currently there is an attempt to remedy this by establishing an incubator centre in one of the heartland areas of Welsh opto-electronics (St. Asaph), which will provide a protected environment for the creation of new firms out of higher education.

5.5 Regional policy and initiatives in Thuringia

Because of its federal structure, many government tasks in Germany are performed by the *Länder*. But because of the particular circumstances in eastern Germany after re-unification, the Federal Economics Ministry (BMWi) and the Education, Science, Research And Technology Ministry (BMBF) initially played an important part initially in planning and implementing technology policy initiatives in the east. In the first instance this concentrated on building up a research and development infrastructure that could operate within a market environment (Hassink, 1996).

For example, in 1991 BMWi launched a network of 21 regionally based agencies for technology transfer and innovation support in the new *Länder*, particularly aimed at SMEs. Thuringia's Agentur für Technologietransfer und Innovationsförderung GMbH (THATI), formed in 1992, is formally part of the three Thuringian chambers of industry and commerce, but a large part of its original funding came from BMWi (Hassink, 1996).

Since the early 1990s Thuringian government support for innovation and technology transfer has expanded considerably. The chambers of commerce were established, as were the development agencies (*Landesentwicklungsgesellschaften*), and the educational system was transformed along the lines of the west German pattern. This included the introduction of *Fachhochschulen* (universities of applied sciences), which are closer to the needs of industry than traditional universities.

The two Thuringian ministries involved in the planning of technology policy and the implementation of federal schemes are the Ministry of Science and Arts and the Ministry of Economic Affairs and Infrastructure. In 1993 they commissioned a panel of experts from industry and science (the 'Sörbe Commission') to make recommendations about the future direction of research and development in Thuringia (Hassink, 1996). This advised the government to focus support on future-oriented technologies and develop industry–science clusters. Two of the four technologies selected are closely connected to opto-electronics (SFTT, 1994). Thus regional policy has actively supported cluster development, including a deliberate intent to locate related industries together – such as ICT and opto-electronics, and biotechnology and opto-electronics.

5.5.1 Thuringian Ministry of Science and Arts

The ministry actively supports research projects as part of this policy to build up regional-sectoral research clusters. Since the end of 1995 approximately DM 35 million has gone into opto-electronic research projects, and nearly all of this has been to companies and institutes in Jena and Ilmenau. There is a concentration of activities at the Beutenberg technology park at the University of Jena. This includes the establishment of a new incubator centre for spin-offs in biotechnology instruments and two new Max Planck institutes. The Institute for Physical High Technology (IPHT) and the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) will also be moving there. It is also the location for TIP (see below).

5.5.2 Economics Ministry

The Thuringian Economics Ministry does not distinguish between particular technologies and does not therefore support industries according to sectors. Its Department of Technology Support is mainly concerned with supporting technology in companies and fostering technology transfer by creating incubator centres. One aspect of its policy is the support for the acquisition and use of patent rights. Thuringia has its own local patent office, the Patentinformationszentrum und Online-Dienste (PATON). PATON is a department of the Technological University of Ilmenau and is the official information centre on patents in the state of Thuringia, as well as the official patent acceptance office.

5.5.3 Stiftung für Technologie und Innovationsförderung in Thüringen (STIFT)

One of the major organisations promoting innovation in Thuringia, STIFT is a co-ordinating body with an objective to support Thuringian technology suppliers and customers by launching technology-orientated projects, helping with project development, fostering the building and development of networks and assisting with infrastructural support. A major task of STIFT is to review projects supported by the Thuringian Innovation Fund (Thüringer Innovationsfond) in collaboration with the Thuringian Development Bank (Thüringer Aufbaubank, TAB) and THATI.

5.5.4 Incubator centres

These centres have been set up with the help of the federal ministries. The most successful one is the Technologie- und Innovationspark Jena GmbH (TIP) (Scherzinger, 1996). Thirty small firms, mostly spin-offs from Jena University, research institutes and Carl Zeiss employ about 160 staff in this centre. It operates like many similar centres in the UK in science parks. There is no particular focus on opto-electronics; in fact, most of TIP's companies are in software and environmental technologies. However, the local presence of companies such as Carl Zeiss and Jenoptik means that the tenants of TIP have opportunities to become suppliers and customers for opto-electronic products.

5.5.5 OptoNet

Alongside this public infrastructure, OptoNet is a new body, formed in June 1999. It is similar in some respects to the Welsh Opto-electronics Forum, but it has greater emphasis on the specific objective of influencing university education and occupational training to meet the needs of the opto-electronics sector. It has some 45 member organisations, including Jenoptik, Carl Zeiss Jena, the Fraunhofer Institute (IOF) and STIFT. In a similar fashion to WOF, OptoNet received some initial support from government funding (DM 3 million per annum for an initial period of eight years). It is formally constituted, with a board of directors and shareholders. The intention is to extend the network to include representatives from the economy, science base and government, and to develop strategic marketing and information networks to ensure member firms' competitiveness.

Finally, a wide variety of public organisations offer various forms of technical and business support within Thuringia. The chambers of trade and industry provide a range of services and management assistance to companies. As elsewhere in Germany, compulsory membership of chambers of commerce ensures that firms are aware of the services available and are encouraged to use them.

5.6 Summary

Cluster-based policies are at the heart of regional government strategies for regeneration in both Wales and Thuringia, and both are endorsed at the national level. In Wales, however, this has a more 'opportunistic' character, whereas in Thuringia the idea of clusters is rooted in wider industrial policy and strategy.

In a comprehensive review of cluster policies in OECD countries, Boekholt and Thuriaux (1999) note that in many countries a broad set of initiatives, ranging from cluster-mapping studies to inter-firm network brokerage, has been launched by national ministries, regional development agencies, local and regional governments, business support organisations, and businesses themselves.

Boekholt and Thuriaux (1999) specifically put Wales into the 'regional development' category, based on their observation that the measures introduced in Wales involve a mix of policy tools that focus on 'strong sectors in their local economy, either in traditional areas or in areas, which are emerging through knowledge strengths or inward investment'. This requires active involvement from the WDA in the promotion of the region and is reflected in its ambitions to get Welsh technological expertise recognised on the global stage.

By contrast, Boekholt and Thuriaux see Germany as an example of the 'industry-research' model, since they consider that 'networks and inter-firm collaboration are stimulated in order to make better use of (public) knowledge resources or to conduct joint research'. The range and extent of knowledge transfer agencies and research-oriented organisations is clear testimony to this, and as Boekholt and Thuriaux point out, Germany has a long tradition of policies to support collaborative research delivered through the agency of the intermediate institutions. Support for regional high-technology clusters is an extension of this, with a further development being the attempt to create multiple interlocking clusters, as in the designation of Jena as a 'bio-region' to add to its opto-electronics focus.

Turning to the impact of these policies, the next chapter considers how firms themselves evaluate the different approaches and support available in the two regions, before reviewing this in the final chapter in the light of firms' experience of innovation.

6 How companies view government support

6.1 Introduction

Having described the support available to firms through government agencies and schemes in Germany, the UK, Thuringia and Wales, we now assess the value of such support through the eyes of the firms themselves.

In both regions governments recognise the need to involve industrial and academic interests to frame practical policies, and there has been considerable consultation before local policies were finalised. The viewpoint of innovative enterprises therefore clearly matters.

In the company interviews, having discussed the product development process in relation to specific innovations, and company strategies towards innovation in general, we then asked interviewees' views on the value and effectiveness of different kinds of governmental and institutional help, based on past experience and future possibilities. To focus the discussion, we specified a range of alternatives under the broad headings of resource support and learning through knowledge networks, referred to here as 'technology transfer'.

Table 4 overleaf shows how these different kinds of activity and support relate to the innovation process.

6.2 Resource support in Wales

Here we report the comments of the case companies on the use they have made of the various forms of resource support available to them, and how they evaluate this.

6.2.1 Government grants and loans

Direct financial support from government sources of all kinds, for research and development, has always been regarded as an important element of the innovation process. Four out of the six case companies in Wales acknowledge this to be the case. This has served several purposes:

1. To get research activity off the ground that would otherwise have not been started
2. To give credibility to research activity that subsequently attracted more substantial funds from private sources
3. To provide funds to keep the company going at a critical time.

Table 4
The innovation system for resource support and technology transfer

Resource support	Finance **Government grants and loans**	**Speculative funding for early stage exploratory and pre-competitive research**		**Selective assistance for expansion if employment benefits are envisaged**	**Funding for promotional materials and attendance at trade shows.**
	Venture and risk capital	**Early stage 'business angel' seedcorn finance to fill gap before venture capital**	**Substantial funds to support these critically expensive middle stages** **Normally entails management involvement and return over five years**		**Funding for promotional materials and attendance at trade shows.**
	Corporate capital	**Speculative funding from corporate parent**	**As with venture capital, substantial funds to support critically expensive stages** **Normally entails management involvement and may result in company spin-off**		**Funding for promotional materials and attendance at trade shows.**
	Marketing support	**Market research**	**Product evaluation**		**Sales promotions, regional PR and trade events**
	People and skills	**High scientific content requires expertise from a small number of key staff**	**Combination of scientific and engineering expertise**	**Need for specialist labour often means developing skills in-house**	**Business orientated engineers to combine technical and market skills**
Innovation process		Research and development	Prototyping	Manufacturing	Marketing and sales
Technology transfer	Incubator centres	**Protected environment for research and early product development, and possible source of partner companies for collaboration**			
	Centres of expertise	**Source of ideas for new products, plus expertise and equipment to help produce and evaluate prototypes**		**Source of expertise to solve manufac-turing problems**	
	Technology clubs	**Source of information on related technology**	**Potential source of partners for collaborative product development and manufacturing**		**Collaborative marketing**
	Technology transfer agents	**Assistance with intellectual property rights issues and the innovation process**			**Assistance with marketing and licensing arrangements**
	People transfer	**Expertise from educational institutions can provide new knowledge at any stage of the innovation process, through exchanges of faculty and students**			

For example, WB has had several grants from the DTI and other institutions:

> '[These have been] crucially important. Over the years both the Welsh Office and the DTI have helped us on numerous occasions – sometimes with quite small amounts of money, but this has often been a key element in getting commercial money. They perform a very valuable service as a catalyst: if you can convince the DTI to invest in your technology, you stand a much better chance of getting a merchant bank to invest very large sums of money. We have done this on a number of occasions. Cwmbran Development Corporation probably gave us the biggest amount of help (£1.5 million) to set up the expansion plant in 1986.' [WB]

However, companies are aware of a change now in funding policy and structure. This was signalled in the government White Paper published in December 1998, which switches the emphasis of funding support from direct intervention towards schemes that facilitate knowledge transfer.

The implications of this are recognised in the Welsh cases. For example, WD in the past would have relied on customers and government grants for development finance (with some exceptions that were financed in-house). This is now changing as collaborative product development projects work on the basis of a shared financial contribution. Thus LINK finance was central to the development of a major new processing capability at WD.

Companies recognise the virtue of companies themselves contributing to the costs of projects. For research in the public arena WA will seek funding from government bodies, including the European Union. But one of the perceived problems with public funding to support 'disinterested' research is that 'projects can often go astray and not develop useful results'. An industrial partner, contributing practical expertise, ensures the outputs from research are more likely to be commercialised.

6.2.2 Venture and risk capital

A distinctive requirement of technology-based firms at an early stage in their growth is for genuine risk capital. Amounts required may be relatively small, but investment time periods may be long. Classic venture capital (VC) should provide the answer, but the VC industry in the UK has tended to focus less on early stage investments (especially for technology) and more on management buyouts (Bank of England, 1996).

Consequently just two of the six Welsh companies (WA and WB) had made use of venture capital. Even here, in both instances, the source of funds was corporate rather than institutional. In one case the money came from a global energy company, in the other from a media conglomerate with a vested interest in having a stake in the emerging technology (a relationship that did not work well, however).

This points to inefficiencies in the market, which can be addressed in part by encouraging investment by business angels in partnership with seed capital funding. Corporate venturing offers considerable scope, and banks have an important role in providing working capital and longer-term loans. However, improving the financing of technology-based firms requires a partnership between public and private sectors, based on an acceptable distribution of risks and returns.

This coincides with views expressed by the Welsh Opto-electronics Forum (WOF), which sees the WDA as having a role in promoting the opto-electronics industry, thus creating a more favourable climate for risk capital to come in. But WOF also wants the WDA to be an instigator of local VC funds. Such a resource only became available in Wales in 2000 with the establishment of a new Small Loans Fund.

6.2.3 Corporate capital

The most obvious form of corporate capital is internal funding from a multinational parent for local subsidiaries' research. Since four out of the six case companies in Wales are part of such organisations, not surprisingly they rate corporate finance as important. However, there is a notable tendency to want to finance developments through in-house funding, if at all possible, which goes with the attitude not to be reliant on government grants that could discourage financial disciplines:

> 'Financial support for product development has never been a problem with us, because we have always been technology-led. We only choose developments that result in directly measurable increases in business. We do not do research and development for its own sake. Financial support is not usually an issue because once your argument is right, you will get the money. It comes from within the group, but whatever stage of life we have been in, we have always been able to finance R&D from our own resources.' [WC]

Other forms of corporate capital such as internal or external corporate venturing are not commonly used by Welsh opto-electronics companies.

Overall, then, the most favoured form of finance for research and product development is one closely related to the business case. For more speculative funding, the search is on for governmental funds at UK and European level, but these are seen as not easily achieved. Although WA has been dependent on venture capital support from the start and since flotation has become equity-based, its attitude sums up that of most of the Welsh firms:

> 'The best funds you can get are from the customer. If you can get the customer to pay up front for research and development, it shows commitment and gives you something to go for'. [WA]

6.2.4 Marketing support

The attitude of Welsh companies to marketing support is summed up by the following comment:

> 'If you do not get your marketing right, you have a problem. So it is essential [that] you have this capability in-house. Support for missions overseas and exhibitions is useful, but this is not the key to successful marketing.' [WF]

The only firms seeing value in more collaborative efforts are WA, which would like a centralised database on Welsh companies, and WE, which values financial help for exhibitions and would like help in developing marketing materials. However, WOF has opened up new possibilities for collective promotion of the region.

6.2.5 People and skills

In a high-technology company keeping up to date with relevant scientific and technological advances and assessing their commercial potential is a key competence that is typically dependent on a limited number of employees. Having a network of contacts is crucial, and this means having personal access to university research centres, trade conferences and exhibitions, and (where applicable) parent company research departments. All this is highly individualistic and has an industry-wide rather than regional inclination. Wales is well served by an educational infrastructure in opto-electronics, but this is no guarantee that it will be utilised in this way, as the linkages are likely to follow individual intellectual preferences and specialised industry requirements.

The current pattern of graduate level employment is to recruit from outside the region. WOF argues that, with better links to the Welsh university sector, there is the potential for spin-off companies to retain skills from academic research within the region, as well as cost advantages in getting a higher proportion of graduates locally.

At the technical and operational level, much of the labour force is recruited locally and trained up internally on the production equipment in use. But concerns are expressed about future skills availability. This is in part be due to the very specialised nature of the work, but some irritation is expressed about WDA policies on inward investment, which are seen as having the effects of increasing competition for skilled staff and focusing on low-skill jobs to alleviate short-term employment problems:

There is clearly a need to co-ordinate local training provision so that it serves the particular needs of the opto-electronics industry. However, these needs are either very diverse or, where they are not, firms are in competition for common skills. Both issues arguably reflect a lack of critical mass in the industry and undeveloped provision of training and skills generally. One consequence is a dependence on in-house skill development:

> ‘People development is an important issue for us. We are always looking for good people but expect to have to train them ourselves. We have tried to get together with other optics companies to get the local technology college to set up an optics course, but we have not succeeded because we compete with each other. The development of a pool of core skills in the area by someone would be beneficial. On the optical design side the situation is actually getting worse as university departments are closing down their optical design courses.’ [WF]

6.2.6 Summary

As Table 5 indicates, Welsh firms rely heavily on national sources of finance throughout the innovation process, whether it is from government, the private sector or a parent company. Local sources are only drawn on for other purposes, such as expansion, although this can provide significant help. However, local agencies perform a useful role in the innovation process in helping local firms to access external funding. While external support for marketing is not generally seen as useful or necessary, training is regarded locally as a problem and is an important topic for the cluster to consider, with the aim of agreeing on common needs and provision in colleges in the region. A considerable skills base has been developed through past recruitment to the area and in-company training, but this is not necessarily sufficient for the future.

Table 5
Summary of use made of regional and national resource support in Wales

Type of resource	Use made of resources regionally and nationally
Government grants and loans	• Direct financial support at the regional level from the WDA has historically been in the form of structural funds related to inward investment or manufacturing expansion (i.e. where there is significant, visible employment generation). • For funding more directly related to product development, case companies have gone to UK sources: – One company (WE) made use of a SMART scheme (a central scheme, delivered locally) for early product development, and two of the more established companies made use of national schemes. These were regarded as providing limited 'pump priming' for attracting further funding (WB). – More substantial funding came from LINK (notably not from the Photonics scheme) and the DTI. These were co-operative projects (with national partners) on new product developments in established companies (WD and WF). • There is very little evidence of European funding, other than that secured by WA for basic research projects with European industrial and academic partners. WB is now looking at the EU as a source of funding. More recently, WOF has applied for substantial funding from the EU for a new research and incubator centre in North Wales.
Venture and risk capital	• Only two companies have used UK venture capital funds, neither from local sources: one for initial start-up costs (WA), the other for manufacturing expansion (WC). • The venture capital market is not well developed in Wales. There is very little evidence of using banks for funding innovation. Banks are viewed as being risk-averse and this is one of the main problems in getting funding. The WDA is seen as having a pivotal role, both in direct funding of resources and publicising achievements in order to attract private funding.
Corporate capital	• Four of the six firms have experience of funding from a parent company, none of which are local.
Marketing support	• Such help as is used is local, but firms do not make much use of it.
People and skills	• Local recruitment is largely confined to lower-level skills. But as external training provision is limited, firms have to depend on developing skills in-house. Local advice and help on recruitment is greatly valued.

6.3 Resource support in Thuringia

6.3.1 Government grants and loans

With the strength of political will currently being directed at photonics, the problem in Germany does not appear to be a lack of support programmes for high-technology R&D and new company start-ups. Rather, there is a plethora of sources. Every region has its own programmes for support, which vary across the country to the extent that potential partners from different areas may not be able to identify a compatible programme. However, the benefit of this is that programmes are adapted to the needs of the regions, while insulating them from one another's distinctive problems. A wholly national system would make this match far more difficult. Therefore what to outsiders may look like a 'funding jungle' (UKCPO, 2000), may in fact be perfectly clear to insiders.

While firms in Thuringia have generally been able to access such funds, this has not been without difficulties and restrictions, and finance does not appear to be so freely available as might at first appear:

> 'R&D staff are always working on projects for which financial support from public research programmes is vital. Sometimes there have been difficulties in getting proposals through, but we have always achieved at least partial support from these programmes. To get grants it is important to point out the potential for the creation of jobs.' [TA]

TE, meanwhile, has found itself being batted between the two federal ministries (the BMBF and BMWi), with applications rejected because they breached the rules of the particular support programme. However, TE sees federal support programmes as being of great importance, especially a new programme called 'ProInno' ('support of innovation'), although it still believes proposals are processed too slowly. This is a complaint that often arises in both countries, with small firms frustrated because they see important developments being held back through the lack of immediate finance.

6.3.2 Venture and risk capital

The situation here reflects both positives (to do with the system of funding in Germany generally) and negatives (to do with the problems faced by eastern Germany immediately after re-unification). Thus, TC had difficulties after the management buyout in 1991 because of the remoteness of its bank (the largest in Germany), and, by implication, the poor image of east Germany after re-unification, which meant decisions were taking too long. When they moved to the local savings bank, where the management was influenced by the Thuringian state government and its interest in creating jobs, co-operation improved. Other firms have found banks generally not much different from banks in other countries – that is, the system is slow and 'you need patience' [TE].

On the other hand, a number of firms have benefited from a particular strength of the German system of finance and governance – namely, the close involvement of banks in providing funds in exchange for an equity stake in the business. In this way Deutsche Effectenbank in Frankfurt took a 25 per cent stake in TA, with the capital being invested in R&D. This highlights the interlocking of companies and financial interests in Germany, since Deutsche Effectenbank is a subsidiary of Jenoptik. This is another instance of Jenoptik's crucial role in Thuringia: through its acquisition of the west German Deutsche Effectenbank, it has directed funding towards a SME that it has itself spun out.

The way larger and more experienced firms (such as TH) solve difficulties in getting funds for development – through partnerships with other firms, support from state sources, their contacts with banks and co-operation throughout the region and beyond – highlights the network of interlocking contacts that characterises the German system.

6.3.3 Corporate capital

Jenoptik's use of its acquisition, Deutsche Effectenbank, to fund developments in smaller firms it has spun out could also be regarded as an example of corporate financing. UKCPO (2000) noted the value of this form of venture capital in opto-electronics in Germany generally, where the formation of new companies being spun out of established ones adds to the vitality of a region.

6.3.4 Marketing support

Views on the value of marketing support are extremely variable, ranging from those who think the state and the chambers of commerce provide useful support to those who find it 'pointless' or 'useless'.

6.3.5 People and skills

Views on the adequacy of the system for supplying skills are also surprisingly variable. While some say the supply is very good and external training courses meet their needs, others are far more critical. The latter criticisms centre on the relevance of the education curriculum, appropriate qualifications and sufficient supply. Those firms that have spun out from the Carl Zeiss *Kombinat* seem best placed since they have benefited from the Zeiss training and qualification system and, in the case of TC, by having its own occupational training centre. The situation overall is clearly affected by whether a firm's business involves more traditional areas of skills or is breaking new ground.

6.3.6 Summary

As Table 6 indicates, the Thuringian funding situation is in marked contrast to Wales, although concerns about skills are surprisingly similar. Firms depend significantly on government grants and loans, while some benefit also from the unique system of links between companies and banks. Companies do not make any obvious distinction between local and national sources of government money. But while bank finance from outside the region has played an important part in some cases, the strengthening of the local banking system would bring Thuringia more in line with the system of regional banking in other German regions. In the case of skills, as in Wales, effort is being directed at local provision through the schools and universities (although in a more concerted way, in keeping with the influence firms in Germany expect to exercise over the education system).

6.4 Support for technology transfer in Wales

This section considers the use made by firms of resources for technology transfer, how they view them and whether there is any pattern of preferring local arrangements.

6.4.1 Incubator centres

Experience of incubator centres in Wales is limited, as this has not been a major policy instrument for the WDA. As a consequence the case companies showed little interest in this approach to technology transfer. None of the case companies had come out of an incubator centre, and while they could conceptually understand the value of providing support services to new companies, they had little experience of how this might work in practice. The current plan to establish an opto-electronics centre at the geographic heart of the cluster at St. Asaph in North Wales includes an incubator element, and this is generally regarded as a good thing. This is seen as remedying the lack of a dedicated opto-electronics facility for research and innovation in the region and will bring together researchers, business support facilities and start-up companies on one physical site.

Table 6
Summary of use made of regional and national resource support in Thuringia

Type of resource	Use made of resources regionally and nationally
Government grants and loans	• In general the availability of funds at regional, national and European levels for early stage research and development was regarded as good, and certainly as vitally important. However, there was no particular emphasis or preference for local schemes. Some difficulties were mentioned, but this is to be expected as clearly not all proposals for research funds will be successful and firms do not always make applications that observe the rules of schemes.
Venture and risk capital	• The system of interlocking companies and banks that has characterised the German system has clearly begun to make an impact in Thuringia, through the co-ordinating influence of Jenoptik. However, the involvement of bank capital from western Germany highlights the importance of the national system – although TC's reversion to local bank finance shows the importance of developing regional funding to stimulate a depressed area. • Venture capital, in the UK and US sense of this, does not feature at all.
Corporate capital	• While Jenoptik in effect acts as a source of corporate capital (through its bank subsidiary), the role of in-house funding from a parent group is limited because only two firms are in this situation.
Marketing support	• There is not much more enthusiasm for external marketing support locally or nationally than there is in Wales.
People and skills	• The sourcing of skills is very largely local, by virtue of the process by which firms have been created: from the rump of local businesses (in the case of TD and TH) and from spin-offs and redundancies from Carl Zeiss/Jenoptik and local universities/institutes. However, views on the adequacy of this system are mixed.

One of the case companies (WD) has seen new companies developed from within its parent organisation. Having seen the benefits that can come from nourishing new business ideas, WD was one of the advocates for the creation of a local incubator centre.

6.4.2 Centres of expertise

Centres of expertise are probably the closest equivalent in Wales to the intermediate organisations that make a significant contribution to innovation in Germany. The higher education sector represents the largest concentration of technical expertise in Wales, and the WDA has sought to use these skills to generate ideas and prototypes for new products, which could then be taken into the marketplace by industrial enterprises. There are 35 designated centres of expertise across Wales, covering a wide range of new technologies, and each centre is expected to take the initiative in forging collaborative links with local firms.

It is probably too early to judge the effectiveness of designated centres of expertise, but early indications from our case companies suggest that they are hardly used at all, and then only for access to equipment. For example:

> 'Centres of expertise at universities have been used where they have facilities that are better than ours in-house – specifically on analysis using electron microscopes.' [WC]

One of the problems is that, being university-based, such centres need to develop a more commercial approach to the marketing of services, since in some cases firms are simply not aware of their existence. Proximity therefore seems to count for something here: for example, WE has a close relationship with a local university, and WC uses the facilities of companies nearby (for chemical analysis). On the other hand, firms often do search out experts further afield when they need advice or help with solve particular problems: for instance, WB visited Cambridge to investigate the feasibility of electron beam lithography.

More extensive relationships with university (or other) centres of expertise may depend as much on changes in attitudes, perceptions and need on the part of companies. For example, WD advocated the development of more formal relationships with universities to overcome the scaling down of in-house research and give access to non-core technologies. Others recognise that such benefits can lead to a self-sustaining virtuous cycle:

> ‘I suppose that in our particular business, because we are ahead of the pack, we are not that dependent on institutional support. But the more we can use university facilities to develop capability, the better. This could be the start of a virtuous circle, as the more the university equipment gets used, the more skills and knowledge are developed, and this is passed on to students and research workers, and works itself way around into a much better facility.’ [WA]

6.4.3 Technology clubs

The key policy measure in Wales is the Welsh Opto-electronics Forum (WOF). Regular meetings take place on a variety of topics, including technical briefings, with outside speakers and visits to member companies. The involvement of WOF in the Regional Technology Plan is judged to have been a success. A web site (www.wof.org.uk) and an opto-electronics directory have been established, the latter containing details of skills, know-how and equipment in Wales.

In January/February 1998 WOF carried out a survey of member companies to assess whether WOF was of benefit to them, how they rated the various activities and members’ interests for the future. Twenty responses were received from a membership of around 50. The highest response was for the interest and value of technical information (75 per cent), and the lowest was for having won an order following a WOF contact (20 per cent). In response to the question ‘Do you support the proposed future activities?’ 80 per cent responded favourably. The strongest support (80 per cent) was for continuing technology overviews, but all other suggestions received over 65 per cent support, with one exception: ‘continuing to receive information on funds, loans and special schemes’ (18 per cent). Nevertheless, most companies still wanted to hear about funding information relevant to the support of SMEs, including partnerships between industry and academia.

Company responses from interviews on the value of WOF are quite low-key. There is interest in WOF (although it is seen essentially as a North Wales initiative), and there is appreciation that something is happening to develop opto-electronics in Wales. But quantified benefits are hard to come by:

> ‘Technology clubs have done quite a lot, but it is difficult to measure … On the other hand, you cannot overestimate the value of networks in an industry like this. Any opportunity to network is always a good thing. It is a very small industry.’ [WD]

One of the concerns among the cluster of companies in North Wales is that there is no obvious institution that forms a nucleus for it. Having looked at other clusters, members have been impressed by the fact that most have a university at their geographical centre, which has acted as a magnet for industry and inward investment. The North Wales cluster centred on St. Asaph owes its origins to Pilkington Optronics, but the strongest regional academic links are outside the area. This has raised the question whether the cluster needs a stronger physical presence at its centre. The outcome of these deliberations has been the proposal for a St. Asaph-based research and incubator unit.

6.4.4 Technology transfer agents

Firms find little value in public arrangements for technology transfer. For example, WD sees independent technology transfer agents as having limited value in what is often a complicated process involving a number of partners:

> ‘A good example of technology transfer is the ‘diamond turning’ story. This was technology transfer using a mix of different mechanisms: initial interest from our corporate research laboratory; a manufacturing unit (ourselves) left to run with it as a research idea; the involvement of a commercial university research centre; other industrial partners; and government funding’. [WD]

Others point to the obvious fact that such bodies need to be staffed from somewhere, which may simply rob companies of their own technical expertise. As WE point out, ‘We actually lost one or two our staff to go and work for the WDA as technology transfer consultants’.

Trade associations, and the fact that certain parts of the industry consist of quite narrowly defined niches in which people all know one another, make public arrangements superfluous:

> ‘Technology transfer agents are not relevant. There are a couple of very good European optical disc manufacturing forums we go to, and we have hosted meetings here. That’s when we get to speak to like-minded people and pick up ideas. The European optical disc association and the federation of plastic presses (which cover wide-ranging applications) hold exhibitions and closed technical meetings. Every 18 months the meeting will be on this site, and we allow engineers from competing companies to poke around on our site, as we do on theirs in return. If we see anything that is really nice, we ask that company to see if we can licence technology. There’s nothing that comes close locally along these lines.’ [WC]

An interesting development, however, is that some companies (WE and WC) see themselves becoming technology transfer agencies as a commercial venture, working with university centres. WC already partly functions as a technology transfer company.

6.4.5 People transfer

Little or no use is made of formal schemes for technological learning by exchanging people. This comes about only indirectly through normal recruitment and training processes. On occasions staff made redundant in other industries are recruited, and this has been a valuable source of skills in a number of cases (WA and WC). Thus, while WB ‘is increasingly looking for graduates who have skills in using in the latest design and modelling packages, which they can relate to our products’, staff learn by pragmatic means: ‘using equipment, building machines and seeing how they work; reading some articles and getting to understand the basics, then talking with people a lot' [WB]. Examples of taking on students for short periods seem to be 'ad hoc' and driven by resource constraints, rather than as an active learning strategy – as at WE, which supplements its resources 'by taking on people from college on special projects, possibly to do a little bit of programming or some research into laser tissue interaction'.

6.4.6 Summary

The facilities available for, or encouraging, technology transfer are limited in Wales (Table 7). There is fairly strong support for the Welsh Opto-electronics Forum as a means of exchanging information and for a local technology/incubator centre to provide a focus for cluster activities and directly as a resource. The support for this proposal is itself testimony to the value of WOF. There is little or no support, however, for other means of facilitating technology transfer – such as agents (or agencies) for technology transfer – and little exchange of staff and students. There may be sound reasons for this, although lack of experience and lack of opportunities may inhibit the development of positive attitudes.

Table 7
Summary of use made of regional and national technology transfer facilities in Wales

Technology transfer scheme	Use made of technology transfer facilities regionally and nationally
Incubator centres	• This has not been a major policy instrument in Wales. The only example of it working in practice is within the parent of WD, a company that has a tradition of incubating good ideas and then spinning off companies to develop them.
Centres of expertise	• Designated centres in Wales do not appear to be strongly promoted, and opto-electronics firms do not appear to make much use of them. University facilities are used for specialist test and evaluation equipment where these are not otherwise available. There is growing interest, however, in a technology centre for North Wales, which would give a stronger focus to cluster activities. This reflects the need for such facilities apparently to be nearby.
Technology clubs	• The local forum, WOF, is the most significant of the WDA policy measures. It is generally regarded as having been useful for exchanging information on technology and having the potential to act as a catalyst for business development. Although opinions are divided as to the precise way forward, the proposal to create a research institute and incubator centre in North Wales has support.
Technology transfer agents	• There is little experience of technology transfer agents in Wales, while initiatives to acquire or license technology have been by direct contacts through European trade associations.
People transfer	• None of the case companies has made formal use of the national Teaching Company Scheme, although a number (WA, WD and WE) take students on temporary placements or for short-term projects.

6.5 Support for technology transfer in Thuringia

6.5.1 Incubator centres

Incubator centres are highly rated in Germany, but not necessarily for the reasons expected. As TG puts it, they provide 'innovation pools and are also used in approaching customers'. In other words, a local innovation centre enhances the overall technological base of an area and can be used by firms for specialist tasks and in promoting themselves to customers through the additional facilities they can call on. This is echoed by TA and TC:

> 'Incubator centres are particularly important in terms of co-operation with small firms, since they can easily assist in parts of innovation projects.' [TA]

Technology parks in Thuringia are perceived not simply as a way of nursing start-ups, but as providing an opportunity for co-operation with small specialist firms. The only dissenting note is from TH (the largest firm in the sample), which regards them 'as ambiguous, because of the sharing of intellectual property and equipment'.

6.5.2 Centres of expertise

Firms make extensive use of specialist institutes and universities, both locally and throughout Germany, and rate them highly. Thus, TC and TD co-operate with the University of Ilmenau and with The Institute for Physical High Technology (IPHT); TF views universities as 'important as partners'; and TA co-operates closely with the Institute of Atomic Spectroscopy (ISAS) in Dortmund, with a subsidiary in Berlin, and with the universities of Ulm and Heidelberg. An article in the trade press featuring one of the firms illustrates the kind of local co-operation involved and the role of national funding schemes in supporting this:

> 'A small German company is marketing high-speed colour sensors that could rival CCD cameras for a large number of industrial test and control processes. Dielectric interference filters are the key to making the sensors less expensive than CCD cameras. The new sensors are based on research at the Fraunhofer IOF in Jena, and development by a local company.' (Hill, 1999)

6.5.3 Technology clubs

The value of having a critical mass of companies and institutions is illustrated by the way most firms are linked into a range of formal and informal groups for sharing information, knowledge and experience. Thus, TD, TE and TH work with relevant industry associations, such as Feinmechanik und Optik and the electrical engineering association VDI: they are also active in the newly formed OptoNet and involved in 'constant discussion groups and forums with R&D managers of collaborating companies' [TE]. TG particularly values the 'know-how' presentations of experts; while TA uses 'symposiums in-house as a bearer of experience', discussion forums by associations of companies in the optic industry, the 'Innovent Club' (a local association of innovating companies), and OptoNet, which it sees as particularly important. Only TC claims to have no knowledge of OptoNet, although curiously they see technology clubs as 'crucial'.

6.5.4 Technology transfer agents

One of the firms (TB) actually functions as a kind of technology transfer organisation, in that it was set up by a consortium of local SMEs to commercialise research ideas. On the other hand, despite the plethora of transfer agencies Thuringia has set up, most firms either rely on informal sources and contacts with university information centres, professors, 'freelance partners' or chambers of commerce (TE, TG and TH), or they regard official agencies as of little or no importance (TC, TD and TF). We should not forget, however, that incubator centres, centres of expertise and technology clubs are means of transferring technology, rather than intermediaries bringing these sources and companies together. At the same time it is important to remember the importance of informal networking – a lesson that some commentators on science and industry policy have been pushing for years (MacDonald, 1998).

6.5.5 People transfer

The UKCPO has commented on the general system of knowledge and technology transfer in German opto-electronics as follows:

> 'The major means of knowledge transfer from universities to industry is by researchers leaving university to take up employment in industry and by consulting. The standard professorial contract in Germany permits a substantial amount of consulting, apparently without overhead payment to the university, of typically up to one day per week. We saw evidence of a number of long term consulting arrangements, clearly valued by both sides.' (UKCPO, 2000)

This is very similar to the UK system, where most universities also encourage staff to undertake consulting of around a day a week – although, as in Germany, this has to be declared, formal permission is supposed to be sought and the use of institutional property has to be paid for. The German pattern of funding for research, with a very much higher proportion of the research funding coming via the institution rather than being for specific projects, also favours informal relationships with professors.

The UKCPO report also comments on the influence of firms funding chairs to influence the curriculum. The Carl Zeiss Foundation has long supported the University of Jena in this way, and elsewhere in Germany Schott, which operates under the Carl Zeiss Foundation as a business with charitable status, exerts a strong influence on opto-electronics education.

Such close ties between industry and education are evident in companies such as TA and TG, which use students on work placements (especially from the *Fachhochschulen*) to gain access to technology and ideas, and to professors on a contractual basis. The relationships with universities run deeper than this, however, and operate in a variety of hidden ways. Although the firms in our sample and among the wider population of opto-electronics firms in Thuringia do not especially originate as university spin-offs (Hendry et al., 1999), they have a very close relationship due to the longer history of Carl Zeiss Jena's role. The implications of this are well captured in the UKCPO comment on opto-electronics in Germany generally:

> 'All of the small companies we visited were located close to the University or Institute from which the founders either graduated or worked. All of them cited good reasons for wanting to remain close to their roots. In most cases the company still either rented space or used the equipment at the University or Institute. In the case where

> they were using facilities and equipment, the companies were located physically next door. They also cited the importance of face-to-face relationships with the local academic staff in helping them keep up with the latest developments in a field and for informing them about their competitors' activities. Local Universities and Institutes are also a source of well-trained employees for the new companies … In most cases, it seemed that these factors were more important to determining where a small company was located than the availability of grants and purpose built facilities from the local government.' (UKCPO, 2000)

6.5.6 Summary

The physical infrastructure for technology transfer in Thuringia is highly developed and valued, although firms do not confine themselves to local sources (Table 8). The interesting feature of this is the value local incubator centres have for firms outside as a source of specialist expertise for innovation projects and of small firms as potential commercial partners. Networks for information sharing are equally well developed. Locally these consist of rich informal networks, now buttressed by the more formal association of OptoNet. Nationally they involve well-established industry associations in optics and electrical engineering. On the other hand, intermediate organisations that exist specifically to foster technology transfer are not much used. Firms rely on more informal contacts – and, of course, on those facilities (centres of expertise and incubator centres) which deliver technological co-operation.

Table 8
Summary of use made of regional and national technology transfer facilities in Thuringia

Technology transfer scheme	Use made of technology transfer facilities regionally and nationally
Incubator centres	• None of the case companies is from incubator centres, but many value local centres highly as a source of specialist small firm expertise they can use on innovation projects or as partners to serve customers.
Centres of expertise	• Companies were unanimous in their support for centres of expertise and rated their importance highly. Although Thuringia does not explicitly promote the idea of 'centres of excellence', it is certainly implicit and widely interpreted by the case companies as reflecting the value of universities (mainly but not exclusively in Thuringia) as research partners.
Technology clubs	• These are generally regarded as useful for the exchange of technical information, with six (out of eight) companies members of Optonet and many involved in other bodies locally (such as 'Innovent') and industry associations nationally. However, the extent of informal networking and discussion groups locally is equally impressive.
Technology transfer agents	• Although one of the companies (TB) considered itself to be a technology transfer agent, there was little enthusiasm for technology transfer agents and agencies, but a greater appreciation of informal relationships.
People transfer	• Local relationships with academics from *Fachochschulen* are valued as a source of information, along with students on industrial placements.

6.6 Conclusion

The summaries in the preceding sections have highlighted key differences between the two innovation systems. Welsh firms rely far more heavily on national sources of finance throughout the innovation process, whether it is from government, the private sector or a parent company. Local sources are used only for business expansion. Steps have recently been taken to remedy the absence of grants for innovation at the local level, with the launch of a 'Wales Small Loan Fund', but the funding situation is still generally in marked contrast to that in Thuringia. Firms there depend significantly on government grants and loans, while some also benefit from the unique system of links between companies and banks.

In their favour, Welsh firms display a healthy independence and readiness to accept responsibility for their own commercial development – although, as mostly mature companies, their own experience and attitudes may not match the circumstances of younger firms. The Welsh problem, from this point of view, is precisely the lack of new firms being formed, and the weakness of the infrastructure in stimulating and nourishing these may be part of the problem.

Surprisingly, both regions share common concerns about the quality and sufficiency of skills. This is a key issue for joint action through formal network organisations such as WOF and OptoNet.

The facilities for technology transfer are limited in Wales. Although technological centres in opto-electronics and related sciences are spread around Wales, the lack of a local technology research and incubator centre at the heart of the North Wales cluster has come to be seen as a major shortcoming. This is shortly to be remedied. The role of the technology club, WOF, in focusing this need and developing the financial bid to get it built is further testimony to the value of a cluster network.

In contrast, the physical infrastructure for technology transfer in Thuringia is highly developed, and valued. Local incubator centres are also valued as a source of specialist expertise for innovation projects and for housing small firms that could be commercial partners to established firms. In addition Thuringia benefits from rich informal networks locally for sharing knowledge, while OptoNet now gives these a stronger impact for lobbying on key issues such as education and skills. Firms also participate actively in industry associations nationally.

In neither region do firms value, or have much to do with, intermediate organisations established to facilitate technology transfer. This is perhaps surprising in the case of Thuringia, although it confirms the findings of Mason and Wagner (1999) that intermediate organisations for knowledge and technology transfer in Germany are under strain and that few 'electronics' firms have formal research links with the Fraunhofer Institute.

Table 9 highlights the particular strengths (in bold) of the innovation system in the two regions and the weaknesses (in lighter print). Where firms are indifferent to resources and institutions, all mention is omitted.

Table 9
Strengths and weaknesses in the innovation system for resource support and technology transfer in Wales and Thuringia

(Note: Strengths are shown in bold print, weaknesses in light print)

Resource support	Finance **Government grants and loans**	Funding for early stage research in Thuringia **Absent in Wales**		Selective assistance for business expansion in Wales	
	Venture and risk capital		Bank funding to support critical middle stages of development in Thuringia		
	Corporate capital	Speculative funding from corporate parent in Wales	Parent company funding to support critical middle stages of development in Wales		
	Marketing support				
	People and skills		**Some concerns in Thuringia about the quality of scientific and engineering expertise**	**Shortages of specialist labour in both Wales and Thuringia** Reliance on developing skills in-house	
Innovation process		Research and development	Prototyping	Manufacturing	Marketing and sales
Technology transfer	Incubator centres	Incubator centres provide protected environment for new firms and additional local resource for established firms in Thuringia **Absence acutely felt in Wales**			
	Centres of expertise	Valued resource in Thuringia for ideas, expertise and facilities **Absence of local centre in North Wales**		**Existing university resources in Wales may be under-utilised**	
	Technology clubs	Act as valued source of information sharing on technology in both Wales and Thuringia			Value as lobbying organisation in both Wales and Thuringia
	Technology transfer agents				
	People transfer	Exchanges of faculty and students from universities of applied science (*Fachhochschulen*) in Thuringia provide regular flow of knowledge and expertise			

While of some value in highlighting the strengths and weaknesses of the innovation system in the two regions, the companies' testimony needs to be considered in conjunction with what we can infer from their actual innovation processes. This is the principal contribution of this study. The concluding section, therefore, reviews the evidence of Chapters 5 and 6 against that of Chapter 4.

7 Lessons for government from how companies innovate: conclusions of the study

This study has been concerned with the balance between local and global orientations in company strategy in the opto-electronics industry, and the kind of governmental support that is appropriate. The starting point was the observation that regional policy in Wales and Thuringia seemed to have a different focus. While in Wales it was more concerned with linking firms into the global economy, in Thuringia the focus was on developing a regional technology system.

The study has broadly confirmed this contrasting focus, but has also highlighted the fact that the opto-electronics firms in our sample are at different stages of development. As a result, the most important lesson is likely to be what the experiences of firms in the two regions tell us about innovation generally. What lessons for innovation can be derived from the experience of innovating firms at different stages of development?, and what kinds of support and infrastructure foster an overall climate of innovation? This broader frame of reference is necessary if public policy is to be responsive to the needs of all kinds of firms and to the long-term needs of an innovating economy.

7.1 Lessons from firms' innovation

Policymakers have to take on board a number of issues from the innovation process itself:

- Firms' stage of development and the resultant differences in their needs and capabilities
- Markets, hierarchies and networks offering alternative routes for collaboration, and the relevance of transaction costs theory in appreciating the relative merits of these
- The importance of firms participating in multiple overlapping networks to stimulate innovation
- The continuing challenge of accommodating tacit and explicit knowledge, and the kinds of initiatives and structures that can ease this.

The relevance of these observations is to deepen policymakers' understanding and models of the innovation process, so that policy initiatives and institutional structures can be based on a better appreciation of firms' innovative behaviour and of the system dynamics that lead to innovation.

7.1.1 Stage of development

The stage of development a firm is at emerges as a key differentiator in accounting for firms' behaviour and needs. Thus, the Welsh firms are generally older and more mature.

They have more established relationships with customers and more international relationships with other firms. This becomes a significant source of learning about market opportunities. The younger Thuringian firms, by contrast, have fewer relationships with major customers to help them interpret market requirements and give access to global market opportunities. Product development is driven by technology, with companies looking for market opportunities to apply their ideas to. While this is to an extent a common characteristic of new small high-technology firms, it also reflects the process by which Jenoptik 'rescued' the most promising technologies from the dissolution of Carl Zeiss Jena and launched firms to try to develop markets for these. Since these firms are often at the stage of refining their basic technology, their intelligence-gathering is also targeted at technological rather than market developments.

Being geared to customers' requirements, the risk for the mature firm is that its intelligence-gathering is limited to serving present customers. While this may lead to commercial applications, it may also lead to technological atrophy and limit future developments. Excessive dependence on a few customers is indeed the trap many small firms fall into. This closeness to customers is reflected further in the orientation of the Welsh firms to 'design and development' rather than research – or, as a number express it, they are 'engineering' companies. They do research, but it is geared to projects defined by customer requirements and relies rather heavily on their internal resources and own expertise. While this 'engineering' orientation is a commercial strength, it also implies a focus on the immediate picture, which could be limiting.

However, a number of the Welsh firms maintain a strong 'technology watch' and combine this with well-funded, well-organised R&D. There is also a growing recognition that developments in new materials mean they will have to make more fundamental investments in longer-term research, and that this will require collaboration with outside partners. Thus, firms tend to go through a cycle where they (i) initially focus on developing their basic technology, then (ii) stabilise around the needs of particular customers that represent their targeted market before (iii) they have to reinvigorate themselves by periodically renewing their technological base. This is likely to be replicated at the industry level, where early breakthroughs are consolidated and diffuse until further advances in basic science have to be assimilated. This process has been described as one of successive phases of 'convergent' and 'divergent' innovation, with the latter having a disruptive effect on incumbent firms (Tushman et al., 1986).

R&D has to be seen, therefore, as a 'driver for controlled growth' [WA], and, because R&D is inherently risky, a careful balance has to be struck between speculative research and R&D funded by customers.

7.1.2 Markets, networks and hierarchy: a transaction costs perspective

One of the advantages a number of the Welsh firms have in intelligence-gathering is that they are now part of multinational companies. This gives them a window onto wider developments, while they also benefit from specialisation within the parent group. Global consolidation in the industry is thus becoming an ally for smaller firms.

The corporate culture of the UK and USA, which tends to see higher levels of acquisition activity and a greater readiness to consolidate into larger units, contributes to innovation by connecting technological expertise and knowledge of markets in the one company. It is thus an alternative way for smaller firms to access technology and market opportunities, and contrasts with the model in Thuringia, which seeks to foster inter-organisational alliances.

This touches on the debate about the relative merits of markets, networks and hierarchy (Jarillo, 1993). As many studies have shown, small firms seldom collaborate with one another, despite the persistent tendency of policymakers to assume that they should. This is true to an extent also of opto-electronics firms in Thuringia. The resistance to collaboration is, in fact, rational and explicable, as transaction cost theory which underlies this debate (Williamson, 1975) would confirm. For example, collaboration imposes significant management costs in managing external relationships and firms risk losing control of their proprietary knowledge.

We therefore find that, once firms have established customer and supply relationships, they focus their collaboration on these. These are relationships in which the sharing of commercially sensitive knowledge will have become established and embedded as a necessary part of doing business, and where relationships of relative trust will have developed over time. The mutual understanding they develop also increases the level of tacit knowledge required for solving problems. It is not surprising, then, that the Welsh firms, who have longer-established customer relationships, put so much emphasis on these.

Among the Welsh firms thus vertical supply chain relationships predominate through the market and hierarchical (or firm-bound) linkages governed by ownership (both of which are international).

In Thuringia, while relationships through the supply chain also dominate, there are marginally more local collaborations. The reason for this is itself associated with ownership, insofar as Jenoptik and Carl Zeiss retain minority shares in certain companies. The influence exercised throughout the region's opto-electronics firms by Jenoptik – both directly and through its network of institutional relationships – tends to reduce the barriers to collaboration.

Similar examples of a large firm acting as a 'system integrator', organising a network of local firms, can be found in opto-electronics in other countries (Hendry et al., 1999), and in other sectors (Lorenzoni and Baden-Fuller, 1995). However, in this case the primary motive of the larger firm is to minimise its own development risks, as well as gain access to public funds for R&D for the SMEs spun off. This is also explicable in terms of transaction costs, with the network form being superior in these circumstances. If these firms prove successful and develop products and technology that is of use to Jenoptik, we might then see Jenoptik tightening these links, to exercise more hierarchical control through its partial ownership.

7.1.3 Networks within networks

Broadly speaking, the network relationships of firms in Thuringia are more parochial than those in Wales. However, Jenoptik is clear that firms need to develop broader geographical links. The largest firms in Thuringia have therefore made acquisitions, collaborated with customers and extended their collaborations with universities and research institutions outside the region to advance this. As a result, while companies in Thuringia are dependent on partners in the region for pre-competitive research, for commercial links and applied R&D partners in Germany and elsewhere have become more important.

This highlights the importance of firms participating in multiple overlapping networks – or 'networks within networks'. Both intra-regional and extra-regional networks are important and serve different purposes. Continuing innovation thus benefits from a regional technology system **and** from national and global networks.

This 'deepening' of network relationships can be seen within the region itself. Thus, while Jenoptik has close ties with its smaller spin-off firms, the latter see 'micro-firms' in incubator centres in a similar light, as 'innovation pools' that can feed their own product development and act as specialist suppliers. The same principle operates in trying to develop clusters of related industries together – for example, opto-electronics and biotechnology – not because they share a common technology platform (although the software industry serves both), but because there are possibilities for synthesis in some segments.

7.1.4 The changing face of collaboration: the role of tacit and explicit knowledge

The history of firms' collaborations highlights differences between developing a position in a market initially, and the use firms make of collaboration subsequently. The significance of collaboration – why firms collaborate – changes during the lifetime of the firm, as does the nature of the collaboration.

Closely related to this is the nature of the sector and the kind of innovations that predominate. Here we distinguish between autonomous and systemic innovation (Chesbrough and Teece, 1996). An autonomous innovation can be incorporated without any adjustments to the system to which it belongs. The systemic innovation on the other hand requires significant changes to other parts of the system. The implication is that the latter will necessarily involve other firms and is inherently harder to manage.

Creating and manufacturing a systemic innovation means fitting together many pieces of knowledge, and this is a complicated management task. A systemic innovation will consist of a great deal of tacit knowledge embedded in the different elements, and explicating this knowledge will require mutual understanding and co-operation. There is disagreement about the best form of organisation for managing this, involving the respective merits of networks, markets and hierarchies.

While relatively new firms may fall into the category of either 'autonomous' or 'systemic' innovators, older established firms are more likely to be in relatively mature and integrated segments of activity. To innovate in this context requires a distinctive approach. Myers and Rosenbloom (1996) call this 'radical incrementalism'. This is the process of testing radically new concepts through a series of practical market learning experiences.

The marked tendency of Welsh firms to innovate through collaboration with customers is indicative of this approach. As we have seen, though, such customers are likely to be geographically distant. At the same time, while these have worked well in notable instances in the past, continuing to rely on established customers to drive their innovation runs the risk of 'lock-in' (Camagni, 1991; Grabher, 1993). As mature firms, they need to reinvigorate their technological base, either by accessing technology in other parts of a parent company or by engaging with outside research institutions. All of this presents significant challenges in linking explicit and tacit knowledge. A regional concentration of firms, technology and research has the potential to ease these problems by grounding some of these relationships within the locality, in face-to-face interactions.

The forms and extent of collaboration change over time, therefore, and with this the challenges of integrating tacit and explicit knowledge within the innovation process.

7.2 The adaptation of policy

Chapters 5 and 6 identified particular strengths and weaknesses of the policy system and institutional infrastructure in Wales and Thuringia. Here we highlight the underlying messages from these in the light of the innovation process. These messages revolve around two principal ideas: the concepts of 'systems' and 'redundancy'.

The idea of an 'innovation system' is, of course, not new, and was indeed our starting point. However, our findings reveal some of the hidden aspects in the way a 'system' works. The concept of 'redundancy' comes from Nonaka (1991) and reflects the serendipity and uncertainty of innovation. Essentially, the more possibilities are built into the innovation system – whether it be in sources of finance, in the public research base, in inter-organisational networks or whatever – the greater the chance that firms can access what they need when they need it. The two ideas are thus related, since a system will function better if it contains a degree of redundancy.

7.2.1 Systems for innovation

One of the basic principles of a 'system' is that the parts are joined up. The most conspicuous example of this is the way in which the German system provides comprehensive resource support to companies through all the stages of the innovation process and integrates this with the promotion of learning, networking and knowledge transfer. The system may be overly complex, in institutions and types of funding, but it certainly limits the chance that a firm will fall through the net if it needs some form of support or stimulus. There is a clear determination to reach out to smaller firms and actively engage them in innovation, and there is generous funding for this.

The case examples raise two issues regarding funding for firms. The first concerns the attraction to firms of public funding for innovation. The Welsh firms are rather wary of relying on government finance to support technical development. This contrasts with the focus of policy in Thuringia and the general presumption that such funding is helpful. Instead, the Welsh firms are more appreciative of government support for 'near-market' purposes (such as business expansion) and imply that 'handouts' weaken market disciplines in running their business. While new, small firms may have a different attitude, this view is surprising and needs to be taken seriously. The suggestion that small firms in Thuringia suffer from bureaucracy in obtaining government funds tends to support the soundness of this attitude.

The second issue is whether finance (in the form of grants and loans, public or private) is better delivered locally or nationally. The Welsh firms are almost exclusively geared to national sources (including government, parent company and private lending). Again, this may suit relatively mature firms but disadvantage new and small firms, which are more locally bound. There is a *prima facie* case for believing that locally available sources of finance fill a gap, but this needs to be seen in terms of the overall character of the national system and its institutions, which may work effectively. This includes the extent to which development funds are available through a parent company.

The particular lesson for a systems perspective, however, lies not in these contentious issues, but in the way different kinds and sources of finance reinforce and complement one another. One of the more striking comments was from WB:

> 'The Welsh Office and the DTI have helped us on numerous occasions – sometimes with quite small amounts of money, but this has often been a key element in getting commercial money. They perform a very valuable service as a catalyst – if you can convince the DTI to invest in your technology you stand a much better chance of getting a merchant bank to invest very large sums of money.' [WB]

In other words, public money gives credibility to the borrower and confidence to other lenders, by reducing the perceived risk. The system of interlocking relationships between banks and firms in Germany works in a similar way to strengthen credibility and reduce risk. Lerner (1994) has noted this in the USA, where public funding subsidies, although they may not directly produce faster growth, have the effect of 'credentialing' a company and attracting other money which is necessary for real growth.

A second instance of 'joined up effects' in the way a system works relates to skills. Innovation depends not just on high-level scientific skills but also on the technical skills that ensure a company can deliver its products and prosper commercially and thus sustain continuing innovation. This is a simpler and separate argument from that which sees high levels of intermediate skill contributing to innovation through a more skilful manufacturing process. Both regions, incidentally, show dissatisfaction with the quality and quantity of technical skills.

A third aspect of the system concerns the integration of firms. More attention tends to be given to the ways in which public policy should supplement and compensate for the deficiencies of the market. Less attention seems to be given to the proposition that a market is, by definition, only a market if it is connected up. Thus the policy debate is preoccupied with improving the flow of knowledge and ideas from public research to commercial firms. At least as important, however, is the supply chain structure that binds firms together. SMEs in Germany have traditionally been a source of strength because it performs this integrating role, while the Welsh emphasis on customers as a source of innovation (and even of development funds) amply demonstrates this.

Although the DTI has been running programmes that use the supply chain as a policy lever for a number of years – notably to improve the efficiency of purchasing policies and to stimulate training – it is not clear that it has a very sophisticated model of the way supply chains operate within and across sectors. This is evident in the recent policy to promote 'clusters' focusing on single sectors rather than on the synergies that come from the co-location of related sectors. The WDA has a similar focus. In contrast, cluster policy in Thuringia has had a multi-sector focus from the outset.

A graphic illustration of the micro-processes of market integration is the role of the incubator centre, in which small firms fill important niches supplying specialised services to other small firms. The Thuringian government also gives considerable attention to improving the flow of business and technical services to SMEs. Both of these are liable to be misleadingly grouped under the heading of 'technology transfer', when what they are really about is enhancing the secondary supply chain.

This highlights a fourth issue in how we view a system of innovation. Much is made of the German system of technology transfer, involving intermediate agents to bridge the gap between basic research and firms. In fact, the firms studied in Thuringia had little time for technology transfer agents. On the other hand, like the Welsh firms, they valued greatly the informal networks through which they got exposure to new ideas – including university information centres, professors, 'freelance partners', chambers of commerce, trade associations and the newly formed technology network OptoNet. The fact that they also made extensive use of specialist institutes and universities points to the necessary interplay of formal and informal processes.

The fifth, and final, example of what a properly 'systemic' view of innovation may entail is the vital part played by attitudes in underpinning the system. This was highlighted by the gradual acceptance by the managing director of WF that co-operation with their arch rival, WD, in supporting the development of an incubator centre as a 'common resource' could have mutual benefits. As long as firms focus inwardly on their own technical resources, the regional innovation system as a whole is liable to remain weak because the 'spill-over' effects which other firms can take advantage of are limited (Krugman, 1991). In a recent study Kaufmann and Todtling (2000) have identified this tendency of firms to focus on their own internal strengths as a general and pronounced feature of firms in Wales across a range of high-technology sectors (automobile engineering, electronics and healthcare).

If attitudes towards co-operation to advance common interests are to change, this example shows the importance of a forum such as WOF to focus common concerns and the role of a visible physical resource, or project, to catalyse a change in attitudes. All of this, we may imagine, is taken for granted within the German system.

7.2.2 'Redundancy'

A number of the examples above also illustrate the value of 'redundancy' in the innovation system – for example, multiple sources of finance reinforcing and complementing one another, and a variety of formal and informal processes facilitating technology transfer. The value of redundancy, however, is seen in the basic principle that successful firms work within and make use of multiple overlapping networks – or 'networks within networks'. The issue, then, is not whether regional, national or international network relationships matter more, but that there are a range of options that firms can link into.

It is not that Germany has a stronger regional system, but that it has federal and a regional system which different kinds of firm can link into, according to their size, age and experience. Thus, Germany has a more conspicuous structure for technology transfer, in part because it is regionally devolved, and the institutions and institutes concerned are formally defined as such. In the UK these functions may be more concentrated, in national bodies such as the Defence Evaluation Research Agency (DERA), or attached to other institutions as part of a broader role. Neither regional nor national orientation need be necessarily superior.

However, the example of DERA does illustrate a problem, since DERA has a narrow focus (being concerned just with the needs of the defence industry). First, the outflow of technology from defence into other applications has been notoriously poor in the UK (compared with the USA, where other agencies exist to facilitate such transfer). Second, as a national institution it serves firms in the defence industry effectively, because the defence industry is organised through large national firms (and where smaller firms are involved they invariably work in consortia led by larger firms). Third, the defence industry opto-electronics serves many markets, and other sectors than defence might benefit from similar bodies. Despite the recommendations of the Advisory Council on Science and Technology (ACOST) in 1988, opto-electronics in the UK has been rather poorly served by institutional structures. The absence of these contrasts with Germany (and with other UK sectors, such as biotechnology) where the technology transfer function is clearly defined through a system of intermediate institutions. This makes it easier to allocate specialised resources and renders the performance of roles more transparent. Everyone knows, therefore, how the system works and where to go. Redundancy in a system thus does not mean confusion, but clear options from the different vantage points of small and large, new and mature firms.

7.3 Concluding remarks

The aim of this study was to consider whether globalisation is making local systems of innovation less relevant. If this is true, it could be argued that technology-based innovation systems will become dominated by common technological regimes, and the opportunity for local variation and possible regional advantage will diminish. We compared two approaches. The first stresses the importance of local innovation systems and puts considerable emphasis on developing local skills. The second approach stresses the role of global factors (particularly markets) in innovation systems and suggests that explicit knowledge will be the dominant force. We have shown how these two perspectives can be combined, by considering case examples in the light of a model that sees innovation as a staged process, involving a transition from tacit to explicit knowledge and back again. Development of close relations with customers allows tacit knowledge to be traded, while renewal of the technological base requires wider-ranging search processes with research centres, customers and suppliers, both locally and globally.

Global relations, however, are hard to manage and rely on a degree of serendipity. Globalisation makes it easier for 'best practice' and explicit knowledge to be transmitted across countries. This, however, does not imply that the knowledge will be universally acquired and internalised in the same way, since learning is locally dependent. A key issue for any region is 'absorptive capacity': the extent to which a region has developed local skills and expertise in technology that is connected to new discoveries. Thus, globally explicit knowledge has to be made synergistic with locally tacit know-how.

On the other hand, local tacit knowledge that does not engage with global market opportunities is going to have limited growth potential. Globalisation is a vehicle for the flow of goods and services. The problem that firms and regions have to face is how to turn their local knowledge into internationally competitive products. Some location-specific advantages continue to be of importance, and development of a reputation for expertise in a particular aspect of technology can be one way in which local know-how can be exploited on a wider stage. Foreign direct investment by large global corporations is increasingly sensitive to locally specific advantages, and we can see numerous examples in Wales where the involvement of a foreign partner, or owner, has brought significant advantages.

In the course of our analysis we have highlighted many lessons regarding innovation and the policy response to encourage it. In our conclusion we have reduced this to a handful of basic messages. Our final comments simplify these yet further. Put simply, we suggest that support for innovation needs to be based around the twin tests of 'redundancy' and 'systems thinking' applied to the following considerations, which are taken from firms' experience of innovation:

- Does the system take account of the different needs and capabilities of firms at their different stages of development, and does it address the whole range of these?
- Does it recognise the way firms operate through markets, hierarchies and networks, and does it respect these as alternative routes for collaboration? That is, does it work with the grain of firms' own structures and behaviour, and commercial relationships, which are partly a function of national systems of corporate governance and partly of their stage of development?
- Does it meet firms' needs to participate in multiple overlapping networks as a stimulus to innovation?
- What kinds of initiatives and structures might help with the challenge of accommodating tacit and explicit knowledge in the course of the innovation process?

Of these, the last is probably the most intractable and daunting challenge from the point of view of both policy and innovation management inside firms.

Appendix A
Case research schedule

The case research sought to answer two broad questions relating to the following areas:

1. The product development process in the firms and company strategies for technology and market development
2. The value of infrastructure support for these.

A.1 Company strategies for product development and innovation

The first part of the interviews covered basic information about the firm, its products, revenues and history. We then explored the history of a key product development (or developments), from idea generation through to eventual marketing, and the critical factors experienced at each stage. Interviewees were also asked to reflect on the nature of, and influences on, innovation in the opto-electronics sector generally. Respondents were then asked to explain their company's strategy for product and technology development along a number of dimensions, to provide a common basis for comparison and to focus on key aspects generally thought to be relevant to the process:

> 'A strategy for technology transfer typically includes some or all of the following. For each one (where relevant) please comment (1) on the value they have represented to product development in the past and (2) your view on their potential for the future.'

Research and development – What proportion of your sales turnover is dedicated to research and product development? Is R&D internal or external? What is your firm's attitude to risk investment and length of payback on any investment in new products and technologies?

Intellectual property – What approach does your company adopt towards the protection of intellectual property? What use (if any) does your company make of the patenting system?

Collaborations with other firms or institutions – Has your firm engaged in any collaborations that have made a significant contribution to the product development process? This might be for the purposes of research, product development, production or marketing. Collaborations might be with firms, government departments, universities or other research institutions.

Information technology – What value do you attach to the use of information technology for the development of products? (This question has wide interpretation. It could mean design and simulation tools, networking software to support group working, e-commerce or the Internet for global searches for technology, production or marketing partners.)

Marketing – What has been your overall approach to marketing? What strategies do you adopt when taking products into international markets? How important is it for you to link into global sources of innovation? How important are international markets to you?

A.2 The value of infrastructure support

Respondents were then asked to explain their company's perception of the value of different policy measures, and perceived gaps in the system:

> 'Governmental strategy to support technology transfer may include some or all of the following. For each one please comment (1) on the value (and effectiveness) they have represented to your product development and its commercialisation in the past; and (2) your view on their potential for the future.'

Financial support for product development – Funds for pre-competitive research, early product development and other 'pump-priming' activities (including governmental funds and grants, venture capital, and 'business angels').

Technology clubs – Formal networks of firms and institutions in the industry set up to foster information exchange and collaborative activity.

Centres of expertise – Recognised research centres typically in universities set up to do basic research and promote their capability with a view to working with industry to commercialise results.

Incubator centres – Premises and support structures designed to accommodate and provide practical help for start-up companies.

Technology transfer agents – Individuals (or organisations) set up to promote transfer of technology either from research institutions or by working with companies to identify technology requirements and exploitation possibilities.

Process support – Infrastructural arrangements and mechanisms for supporting the process of technology transfer. This could be support for technology search and exploitation networks, advice and guidance on the processes involved in technology transfer (such as protection of intellectual property) and planning frameworks.

Marketing support – Mechanisms and arrangements for collective marketing (particularly in the international marketplace), ranging from the provision of market research to support for promotional events, literature and Internet exposure.

People development – Mechanisms and arrangements for improving the technical and marketing skills and capabilities of the workforce. In the UK the principal device for this is the Teaching Company Scheme, but other types of secondment that encourage the flow of people from university into industry might be included.

Appendix B
Opto-electronics applications and growth

Photonics is becoming all-pervasive in modern life as a technological enabler in domestic systems, in business, in medicine and in manufacturing, and it plays a crucial role in communications. The field is fast-moving and is diverse and interdisciplinary in nature, embracing a wide range of traditional disciplines. The power of photonics rests firmly on its basic science, chiefly in science and engineering of materials and in quantum optics.

Although optics is pervasive in modern life, its role is that of a technological enabler – it is essential, but typically it plays a supporting role in a larger system.

Thus the field is largely defined by what it enables. With this in mind, it can be organised around six major areas of market opportunity:

1. Information technology and telecommunications
2. Healthcare and the life sciences
3. Optical sensing, lighting and energy
4. Manufacturing
5. Defence
6. Consumer and entertainment.

In **information technology**, progress during the past decade has been extraordinary. For example, just 10 years ago, only 10 per cent of all transcontinental calls in the United States were carried over fibre-optic cables; today 90 per cent are. Meeting the computing and communications needs of the next 10 to 20 years will require advances across a broad front: transmission, switching, data storage and displays. Many capabilities will have to advance hundredfold. Although institutions have access to this rapidly growing, high-speed global telecommunications network, the infrastructure is not yet in place to provide individual consumer access that fully exploits the power of the system.

In **healthcare** optics is enabling a wide variety of new therapies, from laser heart surgery to the minimally invasive knee repairs made possible by arthroscopes containing optical imaging systems. Optical techniques are under investigation for non-invasive diagnostic and monitoring applications such as early detection of breast cancer and 'needle-less' glucose monitoring for people with diabetes. Optics is providing new biological research tools for visualisation, measurement, analysis and manipulation. In biotechnology lasers have become essential in DNA sequencing systems.

Advances in **lighting sources and light distribution systems** ('displays') are poised to dramatically reduce the one-fifth of US electricity consumption now devoted to lighting. Innovative optical sensors are augmenting human vision, showing details and revealing information never before seen: infrared cameras that provide satellite pictures of clouds and weather patterns; night-vision scopes for use by law enforcement agencies; infrared motion detectors for home security, real-time measurements of industrial emissions, on-line industrial process control and global environmental monitoring. High-resolution digital cameras are about to revolutionise and computerise photography and printing, and improvements in photo-voltaic cells may permit solar energy to provide up to half of world energy needs by the middle of the 21st century. These developments will affect energy and environmental concerns on an international scale.

Optics has had a dramatic economic influence in **manufacturing**, particularly since the advent of reliable low-cost lasers and laser imaging systems. Optical techniques have become crucial in such diverse industries as semiconductor manufacturing, construction and chemical production. Every semiconductor chip mass-produced in the world today is manufactured using optical lithography. Other applications include laser welding and sintering, laser model generation, laser repair of semiconductor displays, curing of epoxy resins, diagnostic probes for real-time monitoring and control of chemical processes, optical techniques for alignment and inspection, machine vision, metrology and even laser guidance systems for building tunnels.

In national **defence** optical technology has become ubiquitous, from low-cost components to complex and expensive systems, and has dramatically changed the way wars are fought. Sophisticated satellite surveillance systems are a keystone of intelligence*gathering. Night-vision imagers and missile guidance units allow the armed forces to 'own the night'. Lasers are used for everything from targeting and range-finding to navigation and may lead to high-power directed-energy weapons.

Applications in **consumer and entertainment** are found most extensively in audio and video discs, one of the largest and most lucrative markets. Applications also include cameras.

(Adapted from National Research Council (1998) *Harnessing Light: Optical Science and Engineering for the 21st Century*. Washington DC: National Research Council.

References

ACOST (1988) *Opto Electronics: Building on our Investment*. London: HMSO.

Amin, A. and Thrift, N. (1992) 'Neo-Marshallian nodes in global networks'. *International Journal of Urban and Regional Research* 16(4): 571–87.

Bank of England (1996) *The Financing of Technology-Based Small Firms*. London: Bank of England.

Barker, T.C. (1994) *Pilkington: An Age of Glass*. London: Boxtree.

Blau, J. (1999) 'Jenoptik sparks Jena technology/innovation park'. *Research Technology Management* January: 3–5.

BMBF (1995) *Laser 2000: Förderungskonzept 1993–1997*. Bonn: Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie.

Boekholt, P. and Thuriaux, B. (1999) 'Public policies to facilitate clusters: background, rationale and policy practices in international perspective'. In: OECD (ed.) *Boosting Innovation: The Cluster Approach*. OECD: Paris.

Brusco, S. (1990) 'The idea of the industrial district: its genesis'. In: Pyke, F., Becattini, G. and Sengenberger, W. (eds) *Industrial Districts and Interfirm Co-operation in Italy*. Geneva: International Institute for Labour Studies.

Camagni, R. (1991) 'Local "milieu", uncertainty and innovation networks: towards a new dynamic theory of economic space'. In: Camagni, R. (ed.) *Innovation Networks: Spatial Perspectives*. London: Belhaven.

Cantwell, J. and Harding, R. (1998) *The Internationalisation of German Companies' R&D*. London: National Institute of Economic and Social Research.

Casper, S. and Vitols, S. (1997) 'The German model in the 1990s: problems and prospects'. *Industry and Innovation* 4(1): 1–13.

Chesbrough, H.W. and Teece, D.J. (1996) 'When is virtual virtuous? Organizing for innovation'. *Harvard Business Review* 74(1): 65–73.

Cohen, W.M. and Levinthal, D.A. (1990) 'Absorptive-capacity – a new perspective on learning and innovation'. *Administrative Science Quarterly* 35(1): 128–52.

Cooke, P. (ed.) (1995) *The Rise of the Rustbelt*. London: UCL Press Limited.

Cooke, P., Uranga, M.G. and Etxebarria, G. (1997) 'Regional innovation systems: institutional and organisational dimensions'. *Research Policy* 26(4–5): 475–91.

DTI (1993) *Realising our Potential*. London: Department of Trade and Industry.

Drilhon, G. and Estime, M.-F. (1993) 'Technology watch and the small firm'. *The OECD Observer* 182: 31–34.

Dubarle, P. and Verie, C. (1993) *Technology Fusion: A Path to Innovation. The Case of Optoelectronics*. Paris: Organisation for Economic Co-operation and Development.

Dunning, J. H. (1993) 'Internationalizing Porter's diamond'. *Management International Review* 33(2): 7–12.

EPSRC (2000) *Review of Photonics*. Swindon: Engineering and Physical Science Council.

Freeman, C. (1974) *The Economics of Industrial Innovation*. London: Penguin Books.

Freeman, C. (1995) 'The national system of innovation in historical perspective'. *Cambridge Journal of Economics* 19(1): 5–24.

Ganter, H.-D. (1997) 'Structural change in the German clothing industry and the reaction of firms'. 13th EGOS conference, Budapest.

Garnsey, E. and Cannon-Brookes, A. (1993) 'The 'Cambridge Phenomenon' revisited: aggregate change among Cambridge high-technology companies since 1985'. *Entrepreneurship and Regional Development* 5(2): 179–207.

Ghoshal, S. and Bartlett, C.A. (1990) 'The multinational corporation as an interorganizational network'. *Academy of Management Review* 15(4): 603–25.

Grabher, G.G. (1993) 'The weakness of strong ties: the lock-in of regional development in the Ruhr area'. In: Grabher, G.G. (ed.) *The Embedded Firm*. London: Routledge.

Granstrand, O., Patel, P. and Pavitt, K. (1997) 'Multi-technology corporations: why they have "distributed" rather than "distinctive core" competencies'. *California Management Review* 39(4): 8–25.

Hahn, R. and Gaiser, A. (1994) 'Aktuelle Innovationsprozesse im bearbeitenden Gewerbe'. *Zeitschrift für Wirtschaftsgeographie* 38: 60–75.

Hassink, R. (1996) 'Regional technology policies in the old and new *Länder* in Germany'. *European Urban and Regional Studies* 3(4): 287–303.

Hendry, C. and Brown, J.E. (1999) 'Clustering and performance in the UK opto-electronics industry'. Seventh High Technology Small Firms Conference, Manchester Business School.

Hendry, C., Brown, J.E. and DeFillippi, R. (2000) 'Regional clustering of high technology-based firms: opto-electronics in three countries'. *Regional Studies* 34(2): 129–44.

Hendry, C., Brown, J.E., DeFillippi, R. and Hassink, R. (1999) 'Industry clusters as commercial, knowledge and institutional networks: opto-electronics in six regions in the UK, USA and Germany'. In: Grandori, A. (ed.) *Interfirm Networks: Negotiated Order and Industrial Competitiveness*. London: Routledge.

Hill, P. (1999) 'Sensors cut the price of colour control'. Opto and Laser Europe 62: 32–3.

Jarillo, J.C. (1993) *Strategic Networks: Creating the Borderless Organization*. Oxford: Butterworth Heinemann.

Kaounides, L.C. (1995) *Advanced Materials*. London: Financial Times.

Kaufmann, A. and Todtling, F. (2000) 'Systems of innovation in traditional industrial regions: the case of Styria in a comparative perspective'. *Regional Studies* 34(1): 29–40.

Keeble, D.E. (1994) 'Regional influences and policy in new technology-based firm creation and growth'. In: Oakey, R. (ed.) *New Technology-Based Firms in the 1990s*. London: Paul Chapman.

Kodama, F. (1992) 'Technology fusion and the new R&D'. *Harvard Business Review* 70(4): 70–8.

Krugman, P. (1991) *Geography and Trade*. Cambridge, MA: MIT Press.

Lerner, J. (1994) 'Innovation and the structure of high-technology industries'. In: Burgelman, R.A. and Rosenbloom, R.S. (eds) *Research on Technological Innovation, Management and Policy: Volume 5*. London: Jai Press Inc.

Lorenzoni, G. and Baden-Fuller, C. (1995) 'Creating a strategic center to manage a web of partners'. *California Management Review* 37(3): 146–63.

Lundvall, B. A. (1992) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter.

MacDonald, S. (1998) *Information for Innovation: Managing Change from an Information Perspective*. Oxford: Oxford University Press.

Mason, G. and Wagner, K. (1999) 'Knowledge transfer and innovation in Germany and Britain: "intermediate institution" models of knowledge transfer under strain?' *Industry and Innovation* 6(1): 85–109.

Metcalfe, J.S. (1995) 'Technology systems and technology policy in an evolutionary framework'. *Cambridge Journal of Economics* 19(1): 25–46.

Miyazaki, K. (1995) *Building Competences in the Firm: Lessons from Japanese and European Optoelectronics*. London: Macmillan.

Myers, M.B. and Rosenbloom, R.S. (1996) 'Rethinking the role of research'. *Research-Technology Management* 39(3): 14–8.

Nelson, R.R. (ed.) (1993) *National Innovation Systems: A Comparative Analysis*. Oxford: Oxford University Press.

Nonaka, I. (1991) 'The knowledge-creating company'. *Harvard Business Review* 69(6): 96–104.

Nonaka, I. (1994) 'A dynamic theory of organizational knowledge creation'. *Organization Science* 5(1): 14–37.

Nonaka, I. and Takeuchi, H. (1995) *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. Oxford: Oxford University Press.

Oakey, R. (1994) *New Technology-Based Firms in the 1990s*. London: Paul Chapman.

OLE (1997) 'Germany extends power diode research'. *Opto and Laser Europe* 40: 15.

Paci, R. and Usai, S. (2000) 'Technological enclaves and industrial districts: an analysis of the regional distribution of innovative activity in Europe'. *Regional Studies* 34(2): 97–114.

Porter, M.E. (1990) *The Competitive Advantage of Nations*. London: Macmillan.

Roelandt, T.J.A. and den Hertog, P. (1999) 'Cluster analysis and cluster-based policy making in OECD countries: an introduction to the theme'. In: OECD (ed.) *Boosting Innovation: The Cluster Approach*. Paris: OECD.

Rothwell, R. (1992) 'Successful industrial innovation: critical factors for the 1990s'. *R&D Management* 22(3): 221–39.

Sainsbury, D. (1999) *Biotechnology Clusters: Report of Team lead by Lord Sainsbury, Minister for Science*. London: Department of Trade and Industry.

Scherzinger, A. (1996) 'Forschung und Entwicklung in den Ostdeutschen Agglomerationen Jena und Dresden'. *DIW-Vierteljahreshefte zur Wirtschaftsforschung* 2: 172–89.

Scott, A.J. (1988) *New Industrial Spaces*. London: Pion.

Scott, A.J. (1993) *Technopolis: High-Technology Industry and Regional Development in Southern California*. Berkeley and Los Angeles: University of California Press.

Scott, A.J. (1998) 'The geographic foundations of industrial performance'. In: Chandler, A.D., Hagstrom, P. and Solvell. O. (eds) *The Dynamic Firm*. Oxford: Oxford University Press.

SFTT (1994) *Forschung und Technologie in Thüringen*. Erfurt: Thüringer Ministerium für Wissenschaft und Kunst.

Sheasley, W.D. (1999) 'Leading the technology development process'. *Research-Technology Management* 42(3): 49–55.

Tushman, M.L., Newman, W.H. and Romenelli, E. (1986) 'Convergence and upheaval: managing the unsteady pace of organisational evolution'. *California Management Review* 29(1): 29–44.

UKCPO (2000) *Report on UKCPO/DTI Mission to Germany*. London: UKCPO.

WDA (1996) *Wales Regional Technology Plan: An Innovation and Technology Strategy for Wales: Action Plan*. Cardiff: Welsh Development Agency.

Welsh Office (1998) *Pathway to Prosperity: A New Economic Agenda for Wales*. Cardiff: Welsh Office.

Williamson, O. (1975) *Markets and Hierarchies*. New York: Free Press.

Woodruff, D. (1998) 'Rising from the rubble: How Jenoptik shed its communist past'. *Business Week* 3586: 20–1.