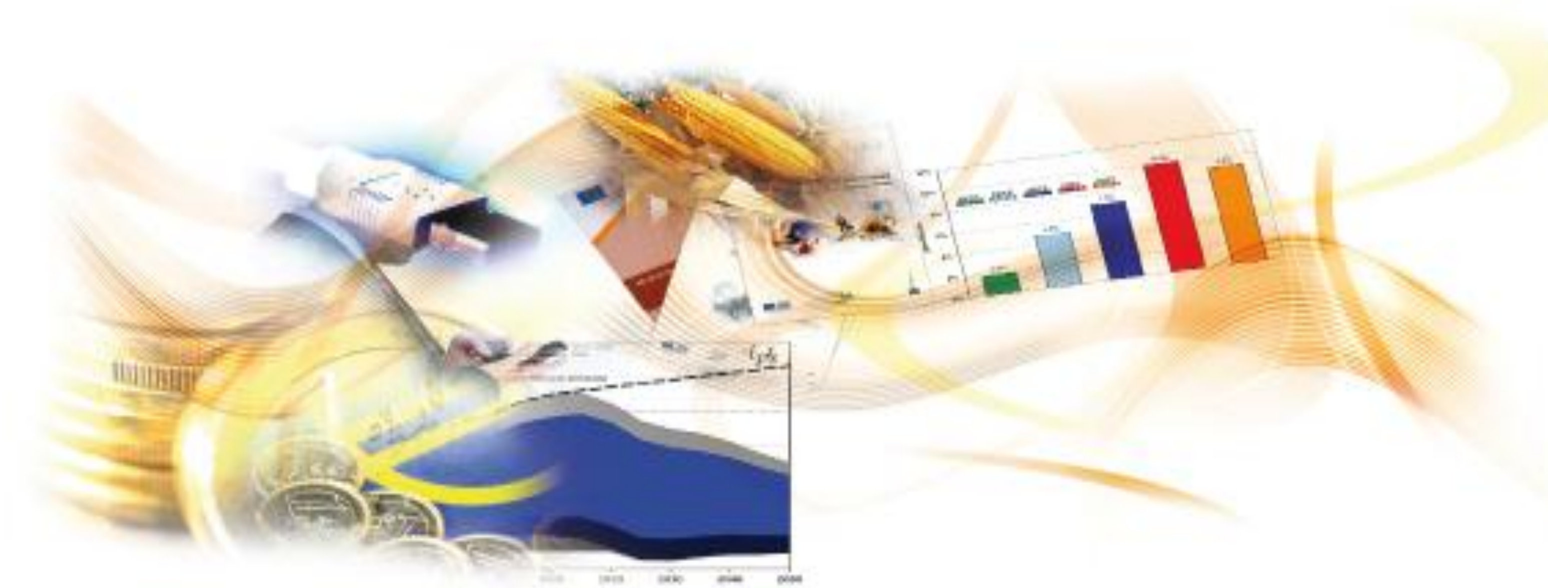

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Comparing Innovation Performance in the EU and the USA: Lessons from Three ICT Sub-Sectors

Simon Forge, Colin Blackman, Itzhak Goldberg
and Federico Biagi

2013

Report EUR 25961 EN

Joint
Research
Centre

European Commission
Joint Research Centre
Institute for Prospective Technological Studies

Contact information
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-secretariat@ec.europa.eu
Tel.: +34 954488318
Fax: +34 954488300

http://ipts.jrc.ec.europa.eu
http://www.jrc.ec.europa.eu

This publication is a Technical Report by the Joint Research Centre of the European Commission.

JRC81448

EUR 25961 EN

ISBN 978-92-79-29825-7 (pdf)

ISSN 1831-9424 (online)

doi:10.2791/13458

Luxembourg: Publications Office of the European Union, 2013

Printed in Spain

Acknowledgements

In preparing this study, the authors would particularly like to acknowledge the guidance and support of Marc Bogdanowicz and Paul Desruelle from IPTS. In addition, the report benefitted from discussions at an expert workshop, "Investigating Industrial and Innovation policies for growth: Contrasting Experts' Views", organized by IPTS in Seville in November 2011. Finally, thorough checking and editing of the text by Patricia Farrer is gratefully acknowledged.

Preface

This report is the result of a study conducted in 2011 and 2012, commissioned by the Institute for Prospective Technological Studies (IPTS)[1] in the context of a research project investigating the issues of growth, jobs and innovation, which have become main priorities of the Europe2020 Strategic programme of the European Union. The report is authored by Simon Forge (SCF Associates Ltd), Colin Blackman (Camford Associates), Itzhak Goldberg (Fraunhofer MOEZ, Leipzig and Center for Social and Economic Research, Warsaw) and Federico Biagi (IPTS, University di Padua and SDA Bocconi).

The objective of the study is to document the existence of innovation gaps between the EU and its main competitors in specific ICT sub-sectors – namely web services, industrial robotics and display technologies –and to explore the role of government policies in Europe's future needs for innovation in information and communication technologies (ICTs) through a comparison with the USA and Asian countries. The overall aim is to contribute to assuring the strong presence of Europe in global high-technology markets by highlighting the measures at an EU industrial and innovation policy level that could correct any failure by Europe in producing commercially successful innovation in the ICT industries.

Our analysis shows that rather than there being a simple innovation gap with the EU lagging behind the USA, a more nuanced picture emerges in which firms in different countries have strengths in different sub-sectors and in different parts of the value chain. For instance, European firms are ahead of the USA in robotics for civilian uses (industrial and service robots), while US firms have been more successful in developing military robots. US companies have been the most innovative in web services. Meanwhile, Asia is much stronger than both the USA and the EU in flat panel displays of all types, used for mobile phones, tablets, computers, TVs and other consumer electronics devices.

A key lesson from the analysis of the three subsectors is the critical importance of higher education, particularly elite university research, and of local networks as generated by clusters. Case studies of Apple, Google and Robotdalen emphasize the importance of prior government intervention to form clusters, from which the start-up can profit. Thus a further role for public policy is to support the formation of clusters, typically a lengthy process, and the result of building on existing strengths. Governments can also encourage innovation through appropriate intellectual property and competition laws and, more generally, through the development of a business environment conducive to innovation. Finally, Governments can have a very important role through the funding of early-stage innovation.

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[1] IPTS is one of the seven research institutes of the European Commission's Joint Research Centre (JRC).

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Executive Summary

Innovation in US and EU companies was analysed in three ICT subsectors (web services, display technologies, and robotics) to develop policy suggestions for best practice for innovation support. Fifteen case studies involving innovation from the three quite different ICT subsectors are given in Appendix 1.

Our analysis shows that rather than there being a simple innovation gap with the EU lagging behind the USA, a more nuanced picture emerges in which firms in different countries have strengths in different sub-sectors and in different parts of the value chain. For instance, European firms are ahead of the USA in robotics for civilian uses (industrial and service robots), while US firms have been more successful in developing military robots. US companies have been the most innovative in web services. Meanwhile, Asia is much stronger than both the USA and the EU in flat panel displays of all types, used for mobile phones, tablets, computers, TVs and other consumer electronics devices. Annual global revenues for the three sub-sectors show their relative significance, with web services estimated at about €70 billion, flat panel displays worth about €75 billion and robotics valued at about €19 billion.

Also note that, generally there are strong contrasts in the difficulties of a start-up succeeding between the different technological sub-sectors in ICTs, reflected by the position of the start-up in the overall value chain for the final product. Enabling technologies in new materials, for example OLEDs or e-ink, which emerge early on in the value chain differ from a product assembled from existing technologies, like the one assembled by Apple, for example.

For a start up, influencing the whole value chain with a basic innovation or change at the start of the value chain for an ICT product or service is much harder than coming in at the end of the value chain. Firstly, the new technology and its maker must influence all that comes later both in terms of players and of their technologies. And secondly, early value chain innovation challenges major industry investments in the upstream value chain sections, which tend to be capital intensive due to their high volume – investors therefore hope that these investments will be long-term. For example, though OLEDs did not expand much in market share between 2009 and 2012, OLED screens of all sizes suddenly started to appear everywhere early in 2012, i.e. when the preceding TFT-LCD technologies had been fully exploited and the industrial investments amortised.

A key lesson from analysis of the three subsectors, particularly web applications, is the critical importance of higher education, particularly elite university research, and of local networks as generated by clusters. Case studies of Apple, Google and Robotdalen emphasize the importance of prior government intervention to form clusters, from which the start-up can profit. Thus a further role for public policy is to support the formation of clusters, typically a lengthy process, and the result of building on existing strengths. In the USA, clusters in Silicon Valley and Cambridge, MA have been building for over seventy years. They require long-term investment in human capital – often around a centre of technological excellence, such as a university, within which there are more specialist centres for deeper research in particular technologies. Successful examples include, MIT's Media Lab, which spawned E Ink, or the Cavendish Laboratory at the University of Cambridge, which spawned both CDT and Plastic Logic. Note that all three companies have since been bought out by overseas entities – a Japanese semiconductor materials company (for CDT), a Russian Sovereign Wealth Fund (Plastic Logic) and a Taiwanese screen manufacturer (E Ink).

The role of government in relation to *collaborative* innovation is to encourage, through appropriate competition laws, which permit shared patent pools for potential innovators under certain conditions, and to encourage joint ventures in research. However, this is not its only role – it should also endorse open source intellectual property in designs and software. The policy suggestion is that much stronger affirmative action for open source is necessary, due to the advantages for innovating enterprises of a solid IP base at minimal cost, with the additional major benefits of the avoidance of litigation threats. This indicates that orienting public procurement towards open source software and design libraries to encourage common shared intellectual capital as a general basis for innovation in Europe has advantages for innovators and governments. It would ensure early sales for innovating companies, while protecting public sector user bodies from the effects of proprietary standards and the price control that accompanies them.

As the case study of Apple, and to some extent Google, has shown, innovation cannot be centred only on technological areas but must also be applied in product and service design. Thus government support for innovative products, processes and services must extend, in education especially, into the industrial and graphic design industries. Note that Apple, the largest company in the world by market capitalization in May 2012, relies on design concepts for its leading position, currently using its British designers and previously its German designers, so that Europe has a strong capability in this discipline that should be reinforced.

The choice of instruments for public funding is important, as exemplified in the robotics case study of Robotdalen and the relevant role of the Swedish government's innovation agency, VINNOVA, This is also emphasized in the case of KUKA in robotics, where long-term innovation has worked well with an effective 'triple helix' of private sector entrepreneurship, various forms of public sector backing and academic support. The crucial role of public funding is confirmed by the case of the USA's iRobot Corporation, which was funded by the Small Business Innovation Research (SBIR) programme, as its business in advanced robotics was considered far too risky for venture capitalists to participate in early funding.

The case studies analysed show that very different factors proved to be essential for corporate success. There is therefore no one policy intervention that could improve Europe's innovative performance but rather a combination of several is needed:

- First, successful innovation depends to some extent on excellence in education and strong and active links between knowledge generation, knowledge exchange and knowledge exploitation (i.e. between universities and firms). From the US experience we know that Stanford University has had a tremendous impact on the emergence of high-tech companies in Silicon Valley, starting with Hewlett Packard all the way to Google.
- Second, to increase the return to these policies, it is necessary to create an innovation friendly environment: low administrative costs, tolerance towards business failure, a friendly business climate, and a large and integrated market (including venture capital). The Amazon case shows the importance of the business environment, the existence of a single market and the efficiency of services.
- Finally, the public sector can provide important financial (e.g. SBIR type instruments, which was crucial in the case of iRobot) and non-financial support. As for the latter, cluster-generating policies have been shown in several case studies to be important.

1. Introduction

This study is part of a larger initiative investigating differences in innovation performance between the EU and the USA. Using a case study approach in three ICT sub-sectors (web services, robotics and display technologies) the study examined the following questions:

- What is the nature of the differences in innovation performance between Europe and the USA in these sub-sectors?
- What are the policy lessons from these case studies?

We tackled these questions by building on previous work, in particular, through reference to selected ICT sub-sectoral studies for IPTS covered in the COMPLETE project.[2] The three sub-sectors were chosen because of the potentially disruptive nature of the technologies involved and because the USA has clear advantage in one (web), the EU in another (robotics) and Asia has the advantage in the third (displays). Evidence was gathered from the practical experience of innovative firms through fifteen case studies – five from each sub-sector. As much as possible we draw on the case studies but, naturally, case study findings may provide only a limited perspective, and so we support our conclusions with findings from the literature where appropriate.

The impetus for this report comes primarily from the case studies, and an overview of our findings is presented in Chapter 2. A more detailed description of the case studies is presented in Appendix 1, with the COMPLETE reports available for those who require a full analysis of the competitive situation in each sub-sector.

Many of our case studies examined small companies as well as large established examples. Of the fifteen case studies, eight were on SMEs (although all of the cases had been SMEs at their initial stage of development): XING in web services; Novaled, E Ink, CDT and Plastic Logic in displays; and in robotics, Shadow Robot, R.U.Robots; we also include the Swedish robotics programme for start-up robotics suppliers and users, Robotdalen. SMEs are of particular interest for several reasons:

- They are often the motor of innovation as they are prepared to follow new business models, pursue new product areas and upset the established competitive balance, without the inhibition of an already successful revenue stream and established market position.
- As their resources are less and their risks in the market are much higher generally, than established companies, support from the private or public sector in keeping them alive is more valuable. Thus SMEs benefit from special conditions, such as clusters, incubators and early support from venture capitalists. In consequence SMEs deserve particular attention when it comes to support for innovation.

[2] Reports on these studies are available at: http://is.jrc.ec.europa.eu/pages/ISG/COMPLETE.html

Analysis of the case studies points to key lessons for successful innovation and forms the basis of Chapter 3, with lessons from the case studies being supported by the economic and innovation literature. Chapter 3 ends with the policy suggestions that emerge from our analysis.

2. US-EU Innovation Performance in Web Services, Display Technologies and Robotics

In this Chapter we put forward an overview of the technological evolution of each sub-sector, specifically with regard to the factors affecting innovation performance in the EU and the USA for:

- Web services,
- Display technologies,
- Robotics.

Annual global revenues for the three sub-sectors show their relative significance, with web services estimated at about $92 billion (about €70 billion),[3] flat panel displays worth about $99 billion (about €75 billion)[4] and robotics valued at about $25 billion (about €19 billion).[5] Our case studies do not support the hypothesis that there is a systematic innovation gap between the USA and Europe in all three subsectors. Similar findings are reported in an econometric study of the EU-US R&D intensity gap by Stancik and Biagi (2012).

Clearly US companies have acquired a dominant position in web services, quickly building on innovative breakthroughs in software, design and new business models (e.g. Google, Apple and Amazon). Even so, there are well–known examples of European innovation in this sub-sector, e.g. Skype. In the robotics sub-sector, while US firms have established a position with military robots (e.g. iRobot), generally speaking it is European firms that have been the most innovative in mainstream industrial robotics (e.g. KUKA, ABB) and especially in terms of innovative new approaches, such as soft, co-working models that seems to offer the potential for the next stage of robotic development (e.g. Shadow Robot). Indeed, the US robotics industry has recently analysed its competitive position and its assessment was critical of US failings in this sub-sector.[6]

Meanwhile, both the USA and the EU have lost ground in flat panel display screen production. Initially both the USA and the EU have contributed significant technological developments in display technologies, jostling for the lead in the early stage innovation in novel screen technologies (for

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[3] SCF Associates Ltd estimate based on the nine top web service providers' revenues in 2010/2011 (with Apple revenue counted as directly online dependent only for 10% of its 2011 revenues of $108 billion, ie adding only 10% for iTunes and other services yields an industry total of $ 92 billion. However this is open to question as all Apple's products are driven by online services, and advertising on the iPad is increasing rapidly. See the web services value chain in Appendix 3 for the verticalization strategy used by Apple, Google, etc).

[4] UK Trade and Investments, 2010, Flat Panel Displays, quotes DisplaySearch, 2009 figures.

[5] SCF Associates Ltd, 2010.

[6] "Unfortunately the United States lags behind other countries in recognizing the importance of robotics technology. While the European Union, Japan, Korea and the rest of the world have made significant R&D investments in robotics technology, the US investment, outside unmanned systems for defence purposes remains practically non-existent" (CCC, 2009).

example CDT and Plastic Logic in Europe and Kodak and E-Ink in the USA). However, neither has been able to retain the impetus to reach commercialized volume production and the resulting rewards, where Asia leads.

Furthermore, it is not until one examines the complete value chain for each sub-sector that one can understand how firms from one country or region can hold important positions in different parts of the chain (see Appendix 2) It is rare for any country or region to dominate all links of the chain in any sub-sector

This analysis supports the view that, in ICTs at least, Europe has had a highly variable success story regarding innovation. The EU has been able to nurture and grow successful companies in some sub-sectors and in some parts of the value chain, so that no general conclusion of 'failure' can be drawn. Instead, in each ICT sub-sector, a particular set of circumstances has led to the current state of play – either relative success or failure compared to the USA (and Asia). Consequently it is more useful to consider that each ICT sub-sector needs its own strategy for success:

- Robotics is probably the most successful sub-sector for the EU and the one with perhaps the greatest potential. In order to bring the next generation of robotics to market in tandem with educating and supporting the customer (especially SMEs) it might be necessary to stimulate the demand side for new "soft robots" with a high safety function, for the promising care and SME markets. The case of robotics also shows that market proximity and real demand is important for early sales and then sustained operations. Hence demand from the automotive sector, for example in Germany, drove early growth in European robotics for industrial types from the 1970s onwards. As a result the EU is quite successful, supplying some 40% of the world's industrial robots with some 50% coming from Asia. In contrast, while the US leads globally by far in military robotics (with iRobot, Raytheon, McDonnell-Douglas, etc) it only produces perhaps 10% of robots delivered for industry, from suppliers such as Adept.
- Display technology needs much more post-innovation effort in commercialization, since the development stages of mass-market products (see value chain in Appendix 2) require 'crossing the valley of death' to initial production and then full-scale industrial volumes for a mass market of displays for mobile phones, tablets and PCs and other consumer electronics. In this subsector the EU has practically lost any initiative, but the USA has also lost out to Asian manufacturers – for instance, Kodak made the first discovery of OLEDs but was unable to commercialize it, while a Taiwanese manufacturer has acquired American e-ink technology for e-readers.
- In web services, however, the USA does lead, owing to combinations of successful first mover advantages, network effects and increasing returns. But even so, Europe has had some success, for example, in niches where culture and language are important, as in professional social

networking (the case of XING). Europe can also innovate successfully at a global level, as the case study of Skype shows. But Skype was seeded by US VC investors and eventually acquired by leading USA web services players, first eBay and now Microsoft.

In the following sections we analyse in more detail the development of companies in the three sub-sectors, and we discuss the lessons that can be learnt from the case studies.

2.1 Web services

For this sub-sector, there is little evidence of direct government intervention having any real impact on the ability of firms to innovate and grow. It is highly commercial, driven by advertising and eCommerce sales of various kinds. Direct research support or public sector programmes aimed at companies are notable by their absence. However, it should be recognized that higher education research funding has led to spin-off companies which have gone on to become highly successful, Google being a good example.

It is a sub-sector where the USA dominates – with the largest players all being first movers – Google in search, Facebook in social media, Apple in music content with iTunes, eBay with online auctions and Amazon in online retail. The cases studies analysed in this sub-sector show that the success stories are based on a combination of two elements. On the one hand we have the development of (or access to) a major technological breakthrough, brought about by ICTs. On the other one, we have the ability to fully exploit it commercially. In this phase, increasing returns and, above all, network effects, are crucial factors and allow firms to achieve effective market leadership quickly.

As for financing, most of the funding that supported growth of these companies has been characterized by three attributes. First, the capital investment required to start an internet-based operation is relatively low. Start-up costs can be minimal because all that is required is a computer and a desk and living expenses for the entrepreneur. Facebook, for instance, got off the ground initially using finance from the founder's parents, to buy servers and support programmers' costs (Kirkpatrick, 2010). Costs will rise in stages but overall the finance needed for a web services business will typically be millions or tens of millions of dollars, and usually a lot less. The tangible deliverable is web software during the early stages. Most capital demands are restricted to web server farms (see the web services value chain in Appendix 2) and even these can be hosted by third party data centres who offer website services for start-ups. Second, in the web services sub-sector, a successful venture will reach break-even and commercial viability relatively quickly, usually less than five years. Or, put another way, if a web services start-up is not profitable within five years the founders and investors will probably have moved on. Payroll expenses are typically kept low as stock options can be used and also overall numbers of staff may be small – even after eight years of operation, Facebook has only 3,200 staff yet 800 million users (Waters, 2012). Third, as illustrated by these numbers, the rate of growth owing to network effects can be extremely high.

These three attributes make web-based start-ups attractive to VCs and so this sub-sector is characterized by the overriding presence of such investors. As a consequence there is little opportunity and no real need for public sector involvement. Nevertheless, some of the successful examples we see in the USA have certainly benefited from existing cluster effects for which a historical government influence is discernable, e.g. Silicon Valley for Google, Apple and Facebook, Seattle for Microsoft and Amazon. These US clusters have drawn on government local investments for R&D, especially in military projects – the early founding of the semi-conductor industry in Silicon Valley and the 1950s military industrial complex in cities such as Seattle with Boeing. But these clusters are the legacy of investments made from two to five decades before in electronics and avionics, for the aviation and armaments industries in general, beginning first in the late 1930s on the USA East Coast, in the Boston area around MIT, and Princeton, and leading on to the West Coast around Stanford and UCLA.

In contrast, the EU initiatives in web services that are successful tend to occupy specialized niches in the market. For example, XING, has used market knowledge of the German-speaking business communities to differentiate and protect their position against US equivalents such as LinkedIn. Both niche players and globally successful European ventures are attractive targets for acquisition. Skype, for instance, is an example of a successful European web start-up that achieved global pre-eminence and was bought out by US companies. Other relevant cases are in eCommerce of books – national operations in the UK and Germany were bought out by Amazon as a way of extending its competitive profile into new geographic markets and exploiting the presence of local companies with all the market knowledge (including those related to language/cultural differences).

In future web service markets, there may be new application areas (and accompanying business models) with global appeal in which the EU can develop major players. However the low cost of entry, availability of VC investment and speed of innovation seems likely to cement US advantage.

Apple – key lessons

The Apple story is informative both from the point of view of its initial start up and growth as a hardware manufacturer but also because of its later reinvention and move into web services. Apple initially grew out of exchanges of intellectual capital: first, at the homebrew computer club in Silicon Valley hosted at Stanford University which had an open IP culture; and second, after start up, it received its main intellectual capital injection from Xerox PARC in return for shares. Without those two stimuli in its first phase, it is questionable whether Apple would exist today.

What has distinguished Apple in terms of innovation is not so much in engineering but rather more in the combination of three areas: first, creating a rewarding user experience, from its user interface to its packaging; second, expressing it in simple but highly effective design; and third, novel, even revolutionary, business models. Throughout its history Apple has dared to be different, choosing to pursue new paths rather than follow market trends, taking the best in engineering at the time to fulfil its vision. The iPod (with iTunes) is an example of this form of innovation. It is a quite different model to basic engineering innovation, for instance, as in OLED technology for flexible displays. Apple takes a view on what is most important to control internally it and what it should externalize. Thus, although it has acquired two 'fabless' semiconductor companies to lay out its processors, the original processor conceptual design for its smart phones and iPads is Cortex, licensed from ARM in the UK, and the graphics processor may come from NVIDIA.

Apple has always strived to control the whole customer experience and so moving to integrate web services into that experience was a natural course and part of its emphasis on design for ease of use. Underlying this is the aim to lock in the customer from end to end, i.e. device, service and content. The chosen structure of the iTunes website has always been to exploit its ease of use, to make purchase of content effortless through good interface design. Thus the web service, at its inception, was coupled to the software (Apple's iOS) and its hardware, the iPod originally, because Apple had noted the enormous difficulty of using MP3 players, particularly with web services and PCs, at the time. Apple thus moved into web services coupled to its Macintosh range, creating proprietary protocols for access and download from its web content server. The key lesson here is to create verticalization using web services as one component (see Appendix 2 on value chains). Apple was the first to do it – followers are Google with Android and the various Android-based apps stores (with a Google smart phone or tablet possibly soon), and Amazon with the Kindle e-reader and its accompanying tied book format.

Influencing the whole value chain with a basic innovation or change at the start of the value chain for an ICT product or service is much harder than at the end of the value chain This is because, first, the technology and its maker must influence all that comes later both in players and their technologies and, second, early value chain innovation challenges the major industry investments in the upstream value chain sections, which tend to be capital intensive due to their high volume and so hopefully will be long-term investments. For example, OLEDs did not expand much in market share between 2009 and 2012, then in early 2012, OLED screens of all sizes suddenly started to appear everywhere, i.e. when the preceding TFT-LCD technologies had been well exploited and the industrial investments amortised.

Innovations early in the value chain must be accepted by the many other players who come later and so dependencies are high. In the case in question dependencies for acceptance include the end-product seller (e.g. a device supplier such as Apple), device designers, circuit designers, sub-system manufacturers. They may be employed within the product supplier, or be external suppliers to it. In contrast, the end-product manufacturer, being at the end of the value chain, is free when designing for a new product (e.g. a new smart phone) to choose from many competing display technologies. Effectively there is a 'point' decision on whether to go for TFT-LCD (the current display technology) or e-ink or OLED screens, each of which may influence our customers in the market, and the product manufacturer's supply chain, but there is far less basic interaction with the rest of the value chain, which is only intent on supplying the chosen technology.

Thus although any player can make a new upstream technology, its progress is held up until it is accepted downstream, closer to the market. The message is that certain technologies in ICT are bound to be more difficult to introduce innovation to, when they are more fundamental, i.e. they occur earlier in the value chain and affect many downstream products and technologies and so are dependent on many other parties accepting them.

Google – key lessons

Google's success depended on two extraordinary, self-confident and highly talented people unwilling to follow the crowd. Larry Page and Sergey Brin were reluctant or even anti-entrepreneurs. They resisted the conventional commercial thinking of the time about how to monetize their invention. They did this despite not having an alternative. Essentially they took an anti-capitalist stance rather like latter day Hippies. They were determined to do what they thought was right intellectually rather than what they thought would be the best way to make money. They pursued a scientific/engineering model rather than a business strategy – in fact in many ways they were anti-business in their attitude. This reluctance and their values meant that, eventually, a winning formula was found. In resisting the conventional wisdom, they eventually produced the second innovation of AdWords which, combined with the PageRank search algorithm, powered their success.

There is no doubt that, at Stanford, Google's founders benefited from a very supportive and nurturing environment with mentors who were able to protect them and indulge their activities. Mentoring also meant that easy access to the Silicon Valley high-tech entrepreneurial business angels and VC networks. Public funding of basic research had a part to play in the Google success story, but apart from a research grant from the National Science Foundation, it is hard to identify any way in which Google directly benefitted from government support.

The lessons from Google are difficult to translate into policy support for innovation. It seems like a unique set of circumstances. It highlights, of course, the continuing need for public agencies in the EU to identify and fund promising research topics as one engine for innovative ideas. However, perhaps the key lesson is that Europe's institutions and authorities should develop greater tolerance and acceptance of what might be described as unconventional behaviour of brilliant people, as Stanford did towards Google's founders.

Amazon – key lessons

The more advantageous business environment in the USA was a key factor for Amazon's successful start up and growth in its first few years. A large, single market assisted Amazon to bring economies of scale to bear on its low margin business model to establish its competitive advantage. In contrast, the European market for books is fragmented owing to national, or even regional, languages and also national policies, which would have made it much more difficult to start up. Websites would also have had to be language specific for the ordering process. The EU's highly variable tax and business conditions across the 27 Member States contrasts with the largely uniform situation in the USA. In comparison with the situation it faced in some European countries, Amazon enjoyed reduced business taxes in the USA.

By starting in the USA, Amazon also benefitted from more relaxed privacy laws labour laws that allowed flexibility in employing staff according to the needs of the business, and access to a large pool of relatively skilled people. Operating in a low margin market segment, the availability of people with necessary skills and the flexibility to hire and fire staff as needed was a key factor in its early survival and perhaps restricted its start-up location to the USA. Moreover, the literature shows that stricter regulation of labour is correlated with lower labour force participation and higher unemployment, especially of the young (Botero et al, 2004).

The location was also important: in Seattle, Amazon was in proximity to Microsoft, which brought high-level personnel for technical positions, for building and then running web services in vast data centres with fast transaction processing, large customer databases and data mining for refined data analysis, for customer profiling and knowledge of cloud computing platforms. Strong network effects are important in web services – for both viral marketing for retail but also networks of business angels, VCs and others who can support nascent ventures in a variety of ways, for instance, identifying specialist staff to manage large data centres and high performance databases.

Well-developed infrastructure was also important, e.g. the supply chain for physical delivery with its infrastructure of warehousing, roads and airports for national delivery.

The trust of customers is paramount and is higher in the USA than in the EU. Thus American citizens are less wary of giving personal data to private firms. Amazon's customer databases hold names, addresses, telephone numbers, email addresses, profiled preferences and, most important, credit card details of its 137 million customers. The USA therefore proved to be a more conducive environment to launch a business that depended on holding such information with less need to reassure customers over privacy and security.

Skype – key lessons

With Skype, first the entrepreneurial and creative impetus came from two individuals who identified the opportunity for voice over the internet. They combined this with the Estonian engineering talent that they had already identified in a previous venture to start Skype. It raises the policy question of whether you can teach entrepreneurship or are you born with it. How can an entrepreneurial spirit best be nurtured and supported in society?

Officially headquartered in Luxembourg for tax and other incentives (PriceWaterHouseCoopers, 2006), its prime locations were Tallinn (for software engineering), Palo Alto (for VC) and London (for general business). It meant that Skype got the best of all worlds – tax credits in Luxembourg but operations located where the human and financial capital were to be found. Besides Luxembourg, tax credits are available in most other Member States for investment in R&D (European Commission, 2009) or for capital gains on shares in start-up companies.[7]

VC funding was not readily available in Europe and this ultimately led to the centre of its business operation being located in proximity to its investors in Silicon Valley. The availability of venture capital – and experienced venture capitalists – continues to be a problem in the EU. Moreover, the wider role of serial entrepreneurs, business angels and venture capitalists in networking to build innovation clusters is also underdeveloped in Europe, although there are some exceptions, notably around Dresden, Cambridge, in Estonia and most recently around London's Silicon Roundabout. The ongoing policy issue is whether Europe can do more to support its VC industry, to attract leading venture capitalists to be based in the EU.

[7] In a similar vein, there are tax credits for start-ups in this sub-sector in the USA, but whether they are effective is open to question. These are piecemeal actions but the USA does not seem to have a coherent multilevel policy (i.e. national – state – municipality/regional) as some Member States in Europe or Asia would attempt to bring together.

XING – key lessons

Xing is an example of a relative European success in Web services, establishing a social network for professionals similar to LinkedIn. Success has come from high quality management, a well-focused strategy and execution of a viable business model. A good grasp and understanding of the market in which it operates gives its niche strategy a chance to succeed.

It has attracted the support of VCs who provide strong management support and capital investment as it is needed through their various board representatives. High access to funding and to its guiding VCs has been due to XING's reputation for good execution. It is the opposite of the 'here today gone tomorrow' start-up.

XING might seem to be a more risky venture than much larger web service players, such as LinkedIn and Facebook. However it also shows how a determined niche strategy can work. So if there is to be government support for new ventures in the web services sub-sector (with support for clusters, tax-breaks, etc) choosing the far-out, the less likely and the niches and not just the global "me-too" ideas may be necessary. These niches may hold the best chances to thrive against heavy competition from the USA and elsewhere in mainstream web services. It is a strategy that relies on the concept of the Long Tail (Anderson, 2006).

Marketing and customer support quality is a key factor in Xing's strategy – a positive feedback, viral factor which is so important cuts down the marketing costs greatly because the membership recruits new members. It demonstrates that to compete successfully against much larger US competitors, stronger customer relationships pay off.

The safe harbour rules for the exemption of US web service providers from EU data protection laws, under which they gain advantages over rivals from the EU, are a source of unequal opportunity between US and EU web applications. This is an important issue but it is beyond the scope of this study.

2.2 Display technologies

New directions in display technologies – in OLEDs and e-paper – offered a brief opportunity for European firms to re-enter the displays market. Recent developments suggest that the opportunity has been missed. The EU has been largely absent from the displays market for the past two decades. Characterized as a high volume production commodity market, production has moved mainly to Asia, especially Japan, Korea and Taiwan. The current generation of flat panel displays

(LCDs) has required tight cost controls and large amounts of capital investment. In fact to protect themselves, the leading players have been accused of operating in cartels to maintain pricing. [8]

Our case studies show that while the EU has strengths in technology discovery and prototyping materials (e.g. Novaled, CDT, Plastic Logic and Bayer), it lacks the capabilities of Asian industrial product development and investment especially for complex technologies such as OLEDs. Manufacturers from Korea (e.g. Samsung and LG Display), Japan (e.g. Sharp) and Taiwan (e.g. AU Optronics) have demonstrated over the past two decades that they have capabilities far in advance of European and US counterparts to understand the market, to invest massively at the right time, and to continue the technology development to scale up promising technologies for mass production. Now that massive investment in LCDs has paid back, Asian manufacturers are starting mass production in the next generation display screens. LG and Samsung are reported to be investing some $17 billion (€13 billion) between 2011 and 2015 in OLEDs.[9]

Until recently, there were strong incentives to extend the life of the existing technology (LCD). Although new OLED technologies are likely to have lower production costs, initially this represents a threat to manufacturing based on older technologies since investments in plant (about $4 billion/€3 billion per factory) have to be written off. It is perhaps for this reason that a global cartel in LCD screens materialized among the ten largest suppliers controlling 80% of the market. This is now being broken up by judicial authorities in the USA, the EU and Korea with heavy fines,[10] seeding the advent of the OLED era.

Here our case studies show the important role of government intervention. For instance, the Japanese government, through the Ministry of Economy, Trade and Industry (METI), persuaded Sony, Hitachi and Toshiba to merge their advanced display businesses for small/medium screens to form Japan Display, as a bulwark against the market dominators in flat panel makers in Korea and Taiwan. Each of the former players was viewed as being too small to be a global competitor. This new screen maker will convert its LCD fabrication plants to OLED[11] and may accelerate OLED mass

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[8] AU Optronics of Taiwan, the fourth biggest LCD flat panel display maker by sales, was convicted of price fixing in a US court in March 2012 and fined up to $1 billion for participating in a display screen cartel between 2001 and 2006 (Financial Times, 15 March 2012). The EC also fined 5 Asian LCD FPD companies in December 2010 – AU, Chi Mei Innolux, Chungwha and HannStar, all of Taiwan and LG of Korea, while Samsung co-operated to avoid a fine (CRWE News Wire, 10 December 2010). The US Department of Justice fined the six LCD FPD suppliers $860m in 2009 for price fixing (Slashdot, 11 December 2009).

[9] http://www.oled-display.net/samsung-and-lg-display-to-invest-17-billion-dollars-in-am-oled-until-2015/

[10] South Korea fines LCD makers $176m for price fixing, Electronista, 31 Oct 2011. http://www.electronista.com/articles/11/10/31/fines.spread.between.ten.companies/#ixzz1n99iY62a
Samsung, Sharp, others pay $539m over LCD price fixing, Electronista, 27 Dec 2011 http://www.electronista.com/articles/11/12/27/agree.to.help.prosecute.other.lcd.panel.vendors/

[11] TalkOLED, 20 Nov 2011, *Japan Display to convert a 6-Gen LTPS fab to AMOLED?* http://www.talkoled.com/tag/oled-production/

production in a $2.7 billion (€2 billion) investment for both R&D and production. It has also bought Panasonic's Mobara LCD plant to convert it to OLED displays, planning for mass production of OLED screens by 2013. If so, it will be the largest active matrix OLED plant planned worldwide for small/medium panels (i.e. for mobile devices). In this way, the Japanese will build mass market scale in mobile phone and tablet size screens (3" to 12") for the expected market expansion from 2013 to 2016.

Thus the future display screens market is likely to be dominated by the largest Asian flat screen producers, even though much of the early technological discoveries and breakthroughs came from the EU and the USA. For instance, Sumitomo Chemical of Japan now controls the UK's CDT with its OLED IPR. Kodak recently sold its OLED patents to LG Display of Korea, who also acquired some patents from Philips. Meanwhile, other Philips' patents on electronic paper and electronic ink went to PVI of Taiwan, who also acquired E Ink of the USA in 2010, the leading producer of electrophoretic ink technology and materials.

Thus EU and US successes in OLED and e-paper research tend to be bought out by larger Asian suppliers and integrated into their value chain. If they are not bought out, start-ups may struggle or go bankrupt. For example, Philips research led to several corporate spin-offs around Eindhoven in OLED and e-paper technologies that eventually failed, such as Polymer Vision, which went bankrupt in July 2009 although its product was bought out by Wistron of Taiwan in October 2009 for €12 million[12] and research continues under the Polymer Vision brand name. One exception to acquisition by an Asian producer is Plastic Logic, originally from the UK but later headquartered in the USA with US investors. Plastic Logic invested in German production lines in Dresden but it lost out in the initial eBook market as Amazon's Kindle and Apple's iPad showed the limitations of its first generation device. It has recently been bought out by a Russian sovereign wealth fund to set up production in Russia. This is a new direction, with large amounts of capital (in the hundreds of millions of Euros) becoming available for medium high-risk ventures from the sovereign wealth funds typically from the Middle East, Singapore and Russia who wish to acquire high technology industries.

Hence one cannot cite the USA's innovation in displays as being hugely successful, and more so than those of the EU. Apple, HP, IBM, Motorola and other very large US producers of ICTs using displays tend to be users of existing technology, buying it in from others, rarely originators. Moreover, the role of government support in such US innovation, for instance in that of Kodak in electronic ink and OLEDs, is not clearly apparent, although there has been some US military interest in e-paper. Both the EU and the USA have lost out to Asian manufacturers who acquire the

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[12] www.pocket-lint.com/news/28346/wistron-names-polymer-vision- purchaser

necessary IP from EU and US researchers, and who bring the capital investment and large-scale manufacturing know-how together, supported by government.

Cambridge Display Technologies (CDT) – key lessons

The role of higher education hosting leading edge research is once again highlighted by the case of CDT. CDT was established in 1992 following the discovery that Light Emitting Diodes (LEDs) could be made from polymers as opposed to traditional semiconductors by researchers at the Cavendish Laboratory at the University of Cambridge. The case study also highlights the university's lack of capability at that time to respond to the discovery in any meaningful way. Researchers had to pay to register the patent using their student grants, and CDT was only set up when it became clear that the university was unable to licence the technology itself.

CDT also illustrates the fact that the time frame for development and commercialization of different technologies may vary significantly. Companies in different technology areas may need different kinds of support. The time frame for commercialization of web services is typically short, only a few years; for complex technologies and where the market has yet to develop, the time frame may be several decades. Although CDT generated some revenues in its first few years, mainly through licensing, twenty years after foundation it had still to make the breakthrough to mass-market commercial success.

Bringing together the right strategy, business model and finance to overcome technological barriers and scale up the technology for mass manufacturing takes time, especially where there is an "incumbent" technology in which there has been enormous investment, as in the case of LCD. Faith that success will eventually come is needed to ensure provision of long-term stable investment. In CDT's case, in 2007 its US venture capital investors became aware that considerably more capital investment was likely to be needed, beyond the estimated \$250 m (€190 m) CDT had already received. When an attractive offer was received from long-term Japanese partner, Sumitomo Chemical, it was an offer that proved impossible to refuse.

Plastic Logic – key lessons

Like CDT, because Plastic Logic's technology is based on complex R&D in materials science for polymer semi-conductors, it has a long development cycle. In addition, commercialization is capital intensive, and requires complex production facilities, which means it is very different from internet start-ups. Moreover, in a start-up company, it could take many years to perfect new technologies as revolutionary as replacing silicon with plastic transistors for a flexible electronic display. Yet most private investors may not be willing to wait. While angel investors can seed start-ups, innovative companies of this type in need of sustained capital investment over many years. They find it hard to raise subsequent larger rounds of funding and move to industrialization, across the "valley of death". Angel investors have limited capital, while VCs who can offer more money are under pressure to exit their investments in a relatively short timeframe, usually 5 to 10 years (or less). This cannot support capital-intensive product lifecycles. Lack of long-term ("patient") funding is the key quandary. By its nature, such a capital-intensive business cannot produce returns for early-stage investors. Fortunately, Plastic Logic has been 'saved' by a massive injection of £440 m (€530 m) from Russian investors, hopefully a second life for the business.[13]

Furthermore, rather than just producing a new plastic transistor technology, Plastic Logic has concentrated its efforts and resources on a product that uses the technology. Hence it has moved fairly far from its core expertise, in semi-conductor technology into a specific consumer electronics product segment. This is a difficult transition, especially so in a market populated by much larger players that have a protective verticalization strategy. Plastic Logic is trying to enter just one segment of a much more complex value chain for such devices, as our value chain research has shown (see Appendix 2). In these kinds of value chains, competitors such as Apple and Amazon control both content and content distribution mechanisms as well as having highly creative product design teams. In comparison, these competitors have enormous resources, perhaps of the order of a hundred times the financing for product development (over $2 billion/€1.5 billion per year in Apple's case), yet they spend little or nothing on developing the underlying basic semiconductor technology. In these circumstances, it is questionable whether Plastic Logic chose the correct strategy and business model and we may only speculate whether long-term capital investment would have led to pursuit of a different strategy.

Plastic Logic may now have found its "long-term investor" among the *sovereign wealth funds.* Perhaps they may become increasingly important investors in long-term basic technologies which germinate whole new industries such a plastic transistors. Such funds are expanding rapidly in high-risk investments; they are based in countries such as Russia, China, the Middle East and Asia. But they also may have a duty to their home country and so require the resultant industrial commercialization with its production capability to be sited there.

Novaled AG – key lessons

Novaled's position as a leading supplier of specialist materials in the OLED field owes much to Germany's public sector funded centres of excellence. Specialist in-depth research institutes are strong breeding grounds for leading technologies. Novaled's resulted from collaboration between the Technical University of Dresden's Institute for Applied Photophysics (IAPP) and the Fraunhofer

[13] Startup Intelligence, Regional report, *Cambridge, From the Lab to the Limelight*, November 2011.

Institute for Photonic Microsystems (IPMS), both in Dresden. Spin-offs from public sector funded centres of excellence, which can freely take high value IP developed in these state or central-government funded institutions provides the first foundation on which to begin commercial operations.

After start-up, further use of government resources for R&D in funds and additional IPR gives valuable stimulus to grow further, as illustrated by the Rollex process technology project case, where a German ministry funded the R&D, giving the IPR to the companies involved.

E Ink Corporation – key lessons

Smaller players in long-term high technology markets tend to be bought out by the largest players before they can become dominant, as soon as their advanced products and technology, which may be just ahead of the market, move towards being mainstream. When it is clear they are setting the trend, they become prime acquisition targets. This is a natural part of the way in which larger companies acquire new technology. E Ink's technology took a decade to become dominant, for a new segment, e-readers. As soon as the new e-reader segment was likely to become mainstream, E-Ink's technology became highly attractive to larger display screen manufacturers, especially its partner who had perfected and invested in the industrial manufacturing processes.

A further nuance of this syndrome is the need for capital-intensive manufacturing facilities for such technologies, which means that start-up companies will always be at a disadvantage when it comes to production unless they can find fabrication partners for industrial production. Moreover for a new breakthrough technology, several other pieces must be put together, such as driver chips, with their fabrication processes, etc, and so only a company able to buy in other technologies and manufacturing facilities can build the end-product. The start-up becomes a smaller part of the value chain, and so tends to be absorbed by the larger industry players, who do not wish to be dependent on a strategic component technology from a company they cannot control. They gain major advantages in streamlining the supply chain, in order to speed up new product development.

As we have seen with other companies in this sub-sector, centres of excellence within universities – MIT Media Lab in this case – can provide focused and fertile sources of start-ups. E Ink also supports the finding that research into complex molecular structures and manufacturing requires long gestation times for stable products.

Note that in consequence, generally there is a strong contrast in difficulties of a start-up succeeding between different technological sub-sectors in ICTs, reflected by the position in the value chain for the final product.[14] Underlying technologies, at the levels of material science, for example, OLEDs or e-ink, early on in the value chain, are much more powerful than a point product when released on a mass scale in the market but may be much harder to make profits from early on. This contrasts with a product assembled from existing technologies, as Apple did initially in its existence, i.e. taking a position in the final stage of the value chain. Although the Apple Macintosh did break new ground (with its injection of intellectual capital from Xerox PARC) it still relied on supply of the latest technologies from outside Apple (for its bit-mapped screen, floppy disk drive, mouse and M68000 processor) though all was *designed* within Apple, including the single button mouse (Rose, 1989).

Kodak – key lessons

The lessons from Kodak are quite clear. Making discoveries and inventions is only part of the innovation process. Kodak failed to turn revolutionary technologies, including OLEDs, into sustainable revenue sources. In large part, this resulted from its general inability to relinquish a successful business model based on technologies that were being superseded in a classic case of creative destruction. In the words of Christensen (1997): "All innovation is hard. Reinventing your entire business is the hardest innovation of all."

With hindsight, we can see that the development cycle for OLEDs was of the order of 30 or 40 years. On the one hand Kodak's wealth from its film business allowed it to fund ground-breaking research over that time period. However, because it was used to operating in the analogue film market that had hardly changed in almost a century, it could not conceive of how to commercialize OLED technology more rapidly.

The scale of funding needed for mass production of OLEDs is in the billions of dollars. By the time the market began to open up, Kodak lacked funds for that scale of investment. Rather than develop and exit the business in a planned way, Kodak was forced to sell its assets at bargain basement prices as it struggled to stave off bankruptcy. As LCD technology comes to the end of its life, Korea's LG has now acquired significant assets that make it one of the key players in the next generation of display technologies.

2.3 Robotics

In this sub-sector, the EU has been quite successful, supplying around 40% of the world's industrial robots with some 50% coming from Asia. In contrast, while the US leads globally by far in military robotics (with iRobot, Raytheon, McDonnell-Douglas, etc) it only produces about 10% of robots delivered for industry from companies such as Adept. This is partly because of the long

[14] Historically, Pavitt (1984) argued that the sources and purposes of innovation are sector-specific.

development times for successful robotics, which does not synchronize with the returns on investment which tend to be shorter term. Thus more patient long-term investors in Japan, Germany and Sweden have built the dominant players. Interestingly Asia does not dominate globally although there are strong players in Japan, e.g. Denso, Kawasaki, Motoman/Yaskawa, and a few in Korea, e.g. DSME and Hyundai. China is still behind but catching up and Taiwan, just starting and keen to enter, is buying small Korean suppliers.

Japanese future robotics research is fixated on android services robots for a potential future in care and domestic service, for its aging population, a field where Europe is already progressing well with more functional forms of robots rather than humanoid forms. Thus Japan has not yet progressed too far, as the technology has still to develop further and the actual market for humanoid robots may be limited.

The EU has had success in conventional industrial robots and their volume sales, in manufacturing, e.g. with KUKA and ABB. Looking to the future, it is EU research that promises to be most innovative for the next generation robotics, for instance, "soft" or co-working robots for SME assistance and in care robots. EU accomplishments result from well organized, long-term robotics investment programmes (such as Robotdalen) which has emphasized the security that comes from its 10-year investment from VINNOVA as being a major part of its success, as well as local markets in the car industry across the EU which have featured long term R&D investments since 1970s in robotics for production lines. Moreover, the EU had made significant R&D progress in the long supply chain for robotics and leads in certain complex sub-systems such as pattern recognition for vision systems and safety systems and also in some electromechanical components, e.g. servomotors, and safety hardware.

Thus in pure design and manufacture of robots for civilian purposes, Europe leads the USA. Examination of the robotics value chain (see Appendix 2) reveals that over 50% of the value of the robotics industry for industrial purposes is in systems integration. By definition, this is a local business and skill set. Consequently there is a lively local eco-system in the USA for the industrial manufacturing sector, with resellers and subsystem builders for vertical segments in manufacturing and medical, such as Peak Robotics and Applied Robotics of the USA, who integrate on top of standard robot units and may also act as dealers for the largest names. But they are really the VARs and S/Is who install and customise the robots made outside the USA largely. Of course this flourishes well in the USA but it cannot be said that the USA leads here either. All the leading global industrial robot manufacturers, such as ABB and KUKA of the EU, Fanuc and Motoman of Japan and Hyundai of Korea have US branches to offer their own systems integration (S/I) services across the USA. These suppliers have sophisticated networks for channel partners for value added resellers

(VARs) and specialized S/Is. The EU players also sell in Asia and provide S/I services. For instance, the robotics headquarters for ABB (a Swiss conglomerate with many machinery product and service lines) is in Beijing, although much original research and production is still performed in Sweden, as it sees China as the key future robotics market as it moves from human to automated production lines.

iRobot – key lessons

iRobot first demonstrates the role of research within an excellent higher education institution. While the research done by the founders at MIT was not itself commercialized, MIT played an important role in building competency, bringing the founders together and nurturing their early development.

A second key lesson emerges from the need to support the development of products arising from complex technologies over an extended period. The US Small Business Innovation Research (SBIR) programme provided significant funds for the company in its early stages rather than business angel or venture capital. This was because the venture was considered too risky for venture capital investors. "What we were trying to do was so risky that no rational investor would give us money", recalls Colin Angle, chairman and chief executive officer of iRobot.[15] "The SBIR Program would listen because they were looking for innovative research". SBIR awards supported 33 iRobot research initiatives, contributing more than $30 million in funding for the development of new sensors and enhancements to the robots' capabilities. Angle remarked, "I can say with absolute certainty that without the help of the SBIR program, iRobot could not have become the industry leader we are".

If SBIR funding through DARPA was the mechanism to see iRobot through the funding "Valley of Death", it is public procurement that has enabled it to grow and develop into a substantial company and market leader. For instance, in April 2011 it signed a four-year, $230 million contract with the US Navy, and in September 20111, it was awarded a five-year, $60 million contract to supply the US Army with more of its PackBot combat robots.

Shadow Robot – key lessons

Shadow Robot, a small, London-based robotics company incorporated in 1997 but with roots going back to 1987, illustrates both European ingenuity and its inability to support the unconventional. It has developed world-leading technology in its state-of-the-art robotic hand, but commercial success is far from assured.

It is informative to compare Shadow Robot with iRobot. Both started small and with little idea of how to commercialize their know-how. Shadow was not spawned by a higher education institute,

[15] http://www.sba.gov/sba-100/irobot

although actually both Shadow and iRobot appear to have been characterized by similar amateurism in their early stages. iRobot, however, made the transition to a commercially minded and successful company much quicker than Shadow, owing to two factors. First, iRobot's management were talented and leant quickly from their early lack of commercial success to develop a strategy and business plan to achieve their objectives. Second, they found the funds to see it through the valley of death, initially from the US government's SBIR scheme. By contrast, it is only more recently that Shadow Robot adopted the basics of management, changed its strategy and found a measure of commercial success.

Counter intuitively though, the enthusiasm of its founder and the core team and the fact that it has had to survive hand-to-mouth for so long has meant that Shadow Robot has a resilience which has seen it outlive all of the seemingly more credible UK robot projects that received more generous funding over the past 20 or 30 years.

KUKA Roboter – key lessons

KUKA has attained a global market position partially through collaboration in intensely technological fields using research resources financed by local and national government and by the European Commission. This has provided a critical mass of high technological advantage in the global market. The most profitable form of support has been close collaboration with an advanced technology research institute having long-term goals – the German Aerospace Centre (DLR) Institute of Robotics and Mechatronics. DLR is not subject to commercial pressures and so can pursue subject areas which are:

- very high risk with low chances of success, i.e. unlikely to be funded by VC;
- may lead to little or nothing, and are wide-ranging, not necessarily focused, as they may possibly contribute to crossovers in the future;
- contributing to a critical mass of deep research, far more than a purely commercial organization can afford;
- dependent upon open source software and libraries;
- producing a source of high quality staff from academic research.

Looking more widely, KUKA illustrates how Europe has gained a critical mass of intensity in robotics research and so can maintain or expand its global position of supplying some 40% of all robots worldwide by using a 'triple helix' that works between academia, private sector companies and public sector supported institutions. This is a key structure for long-term innovation.

R.U. Robots – key lessons

The analysis of R.U. Robots, a UK SME in robotics systems integration, was interesting at a different level to other case studies, in that the experiences gathered from its key staff afforded greater insights into the overall condition of European innovation and its centres of weakness and strength:

Robotics exhibits slow development, over decades, and high levels of R&D expenditure. It is fairly high risk in terms of successful commercialization. Thus private venture capital is not suitable for funding because of its demand for rapid returns from medium/low risk ventures. Consequently forms of public funding of appear to be the way forward.

Robotics benefits from physical proximity, the geography in clusters. Thus clusters should include the customers for robotics as well as suppliers. Most useful would be a form of government insurance for smaller user companies, as they are averse to new technology, more so than large companies, as they see innovation as high risk. Robotdalen in Sweden does this kind of new user SME support.

Collaborative projects, as in the FP 7 type, are useful for pre-competitive developments for the larger companies who require funding for their R&D. The nature of the subjects, costs of overheads and the limitation to pre-competitive working make them less desirable for small companies. The EC's FP7 collaborative projects are useful for marketing for small innovative companies - but they tend to find that their own innovation processes lie outside the FP7 workings. A new small business research initiative to fund smaller innovators in the EU directly is required.

Threats of legal action over patents are mounting, which act as deterrents to use certain technologies, innovate in them or participate in some projects. Whether infringement actually occurs is often unclear. Open source software (e.g. from Willow Garage, DLR and others) is to be preferred, especially for government supported R&D projects, as it can be shared and so is cheaper for small, innovative companies and avoids problems of IPR contravention.

Robotdalen – key lessons

Robotdalen is a cluster, a form of "robotics valley", running across southern Sweden, providing innovation support for suppliers and users as well as all elements of the robotics value chain. Robotdalen is a local success. Whether this regional cluster can be transferred to being a national or international centre of excellence is still to be ascertained. What it does show is that:

- Clusters in robotics can work successfully, given the conditions below.

- Long-term government funding is major element of success. The security of continuous finance over a decade has ensured constant progress. This is important in robotics, which seems to require a lengthy course of development.
- Robotdalen has focused just as much on the demand side as in pushing innovation on the supply side. Creating a cluster of not just of suppliers and their supply chains, but also of the end-users, of what are still very advanced technologies is key to building up a real market in robotics. But support for take-up of high technology in the relatively untapped SME market means devoting much effort, first to justifying with business case analysis, then to long-term user support.
- Involvement of universities in the seeding process, both for new technological innovation and for driving new technology take-up, is a major factor. This is shown in the use of university staff and even students to introduce robotics through business cases and technical integration services, at reduced costs to new users.
- Concentrated use of the “triple helix” model is rewarding for such initiatives, especially in the Swedish model, with local authorities who participate and fund activities, primarily in order to expand local high-tech employment.

3. Lessons for Innovation Policies

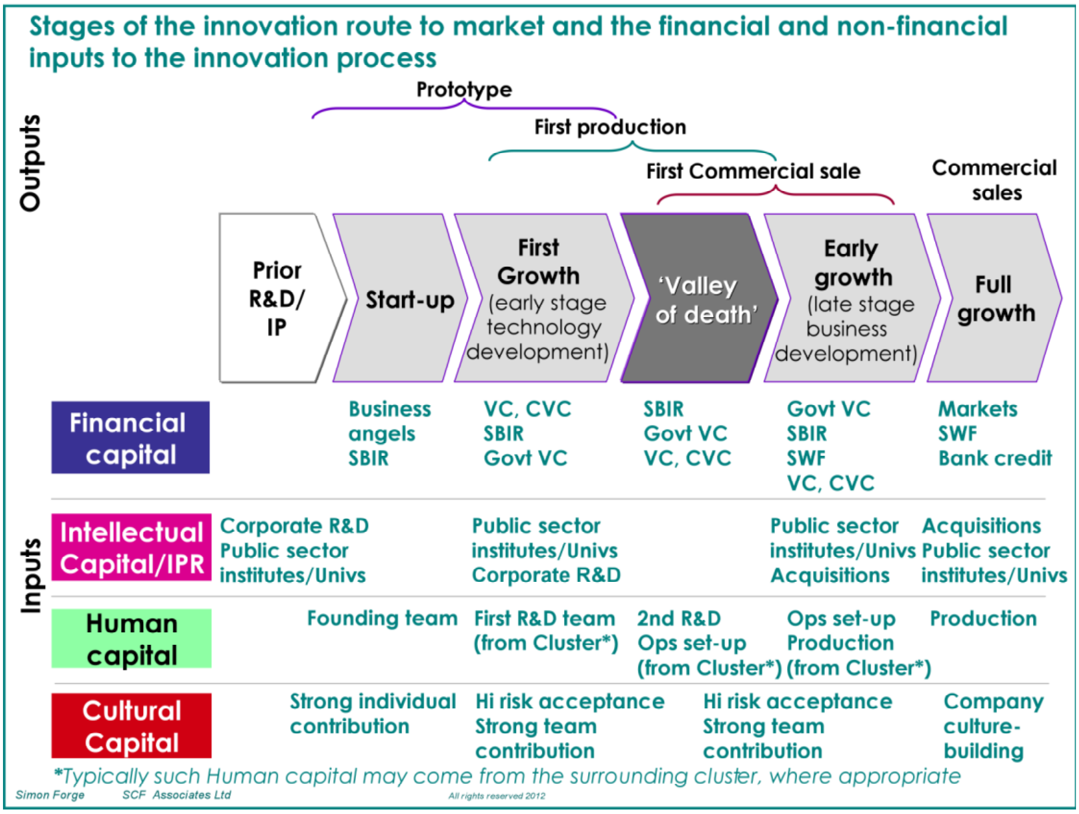
3.1 Key inputs in the innovation process

We have identified in our case studies, four key inputs in the generation of innovation (in economic jargon, factors in the innovation production function):

- Financial capital,
- Intellectual capital,
- Human capital,
- Cultural capital.

In Figure 1, we present six phases marking the development path of a start-up company. This also shows the four key innovation inputs – financial capital, intellectual capital, human capital and cultural capital – as a table, below the phases of development. We then explore each input at each phase. In the cells of the table, we list private or public instruments which support each input at each phase of the development path. For example, financial capital at the critical "Valley of Death" could be funded by a VC, a corporate VC (CVC), a state-owned or partially owned VC and an institution providing grants such as the US, UK or Dutch SBIR.

Figure 1: Inputs to the innovation process



At the Valley of Death stage, intellectual capital which has been created in the two previous phases now forms the basis of production, and so is of less importance than the process of industrialising what has already been created, to make a saleable product or service for commercial sale. Thus in the human capital required in this phase, two teams are now often necessary – an R&D team that can take a prototype and turn it into a marketable offering and a team for industrial operations. At this stage, the latter becomes the primary focus for acquisition of human capital. This team handles industrial scale operations, be it setting up a web farm and then scaling it up to millions of users, or starting up manufacture of a device with a production line (internal or outsourced) as well as procurement with an inward supply chain and a distribution chain out to the market with logistics, marketing and sales, customer care, recycling etc, all of which may be internal or (partially) outsourced. The cultural capital, of risk acceptance, becomes even more important at this stage, as the growth in human capital expands the workforce, perhaps many times, yet the level of risk due to the need for more funding capital, and the uncertainty of market success, is perhaps greater than during the two earlier stages, or the two following stages, when some stability may be expected.

Financial capital

Venture capital

The traditional sources for company financing of long term innovative investment are:

- Retained earnings; this source is relevant for capital investment for both conventional non-innovative projects and also for innovative projects; i.e. large companies investing in their own innovative spinoffs or in outside start ups and mergers.
- Debt financing from banks and non-banking financial institutions.
- Equity and debt financing from stock and bond markets.
- Venture capital.
- Government subsidies: grants, loans, guarantees, tax concessions, VC ownership, 100% or less.

In this section we mostly discuss the role of venture capital in funding web applications in the USA and in EU.

As we see in our case study, Apple Computer was seeded by Mike Markkula, an ex-marketing manager for Intel, whose own $90,000 injection and guarantee of a credit line of $250,000 transformed garage-based Jobs and Wozniak into a business capable of delivering the first order for Apple. 'Smart money' like this is often accompanied by managerial experience and contacts. Successful start-ups undoubtedly benefit from this, as the XING case study, for instance, shows.

Such business angel investment has become more organized as a recognized source of finance for entrepreneurs over the past twenty years, especially for the earlier stage investments (Mason and Harrison, 2010).

Intervention from VCs and business angels comes at a specific time in the start-up's struggle for survival, as shown in the Figure 1. It is in the initial stages of first founding with start-up and then in first growth, continuing, if the venture is lucky, across the "valley of death" into first commercial sales. Yet, as Hall and Lerner (2010) point out, VC has its limitations in financing innovation:

- small and new innovative firms experience high costs of capital that are only partly mitigated by the presence of venture capital;
- evidence for high costs of R&D capital for large firms is mixed, although these firms do prefer internal funds for financing these investments; there are limits to venture capital as a solution to the funding gap, especially in countries where public equity markets are not highly developed.

Internet start-ups are ideal VC investments, as our case studies of Google, Skype and XING show especially for US VCs, characterized by rapid payback with low entry costs and are not capital intensive. Thus web services such as Facebook, eBay, Twitter, etc have been strongly favoured by the VC community. Yet, the US VC industry has been investing in diverse sectors, and not only ICT or web applications and in large companies as well; Lerner (2010),[16] (Table 3.2) reports that "...those public firms supported by venture funding employed 6% of the total public-company workforce – most of these jobs high-salaried, skilled positions in the technology sector. Clearly, venture investing fuels a substantial portion of the US economy". However, the USA has been much less successful in those technologies that require longer term investment and support such as robotics and displays.

One reason why web applications companies have been founded and grown in the USA is because VC funds have been more readily available in the USA, However, the causality can run in the other direction, i.e. VC funds could flourish thanks to the better investment opportunities in the USA (see below in Lerner 2011). A 2011 study for the UK's National Endowment for Science, Technology and the Arts (NESTA) on the VC gap between the USA and Europe, especially the UK, revealed (Lerner et al, 2011):

- The performance gap of VC funds in terms of internal rates (IRR) of return between US and the EU has narrowed, although not because EU funds are doing better. The average returns since 1998 have become closer, because average returns in the USA have fallen; but the performance gap would reappear if US returns improve. Before 2000 and the dot.com

[16] Josh Lerner, Bo*ulevard of Broken Dreams: Why Public Efforts to Boost Entrepreneurship and Venture Capital Have Failed--and What to Do About It* (pp. 59-60). Kindle Edition.

bubble, US venture funds enjoyed average internal rates of return (IRRs) that were higher than those of the EU, varying by country (e.g. 33% v 13% in the UK).

- Government backed funds in the EU have historically underperformed their private sector VC counterparts, but the gap between public and private returns has narrowed, based on recent data from the UK compared with the USA.
- The historical US–EU gap cannot be explained by the characteristics of the funds alone. Even when comparing funds with similar characteristics, the long-standing EU performance deficit persists. And when EU funds invested in the US, they did well. This suggests that an important cause of the performance gap was the existence of better investment opportunities in the USA.

Sovereign wealth funds

A new player in relatively high risk investing is emerging with the growth of sovereign wealth funds (SWFs) that seek to reinvest economic surpluses. Although first formed in the 1950s,[17] since 2000 their number has swelled dramatically. They are generally national state-owned investment funds, often in the developing nations, aiming to invest globally. A total of some $20 trillion of investments is available to governments having SWFs. The capital comes from various financial assets – stocks, bonds, or other financial instruments, property, often from traded commodities, especially oil. Most SWFs use foreign exchange assets,[18] usually for investing in large infrastructure ventures or to take equity in major, stable corporations. However the latter have sometimes proved illusory in their stability[19] and so VC-style investment, in small quantities, is more considered. The largest SWFs are those of the Middle East and Asia such as Abu Dhabi's ADIA with $627 billion and China's SAFE, estimated at $580 billion as well as Singapore's' GIC and Temasek Holdings, or Norway's Government Pension Fund, GPF with $560 billion in assets.

In 2011, SWF assets totalled $4.8 trillion,[20] a record, following increases since 2008. But in addition, some $7.2 trillion was held in other sovereign investment financial entities, such as pension reserves, development funds and state-owned corporations' funds. A further $8.1 trillion is held in other official foreign exchange reserves.

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17 The first SWF was the Kuwait Investment Authority, created in 1953 from oil revenue commodities.

18 *Sovereign Wealth Funds: Generally Accepted Principles and Practices* (the Santiago Principles), International Working Group of Sovereign Wealth Funds, October 2008, http://www.swfinstitute.org/what-is-a-swf/

19 SWFs had poor experiences with Wall Street financial firms including Citigroup, Morgan Stanley, Leman Brothers and Merrill Lynch – losses or cash infusions after mismanagement and the subprime meltdown.

20 The City UK, research, 2012: http://www.thecityuk.com/research/our-work/reports-list/sovereign-wealth-funds-2012/

Sovereign funds can spur entrepreneurial activity owing to their abundant capital resources and long-term outlook (Lerner, 2009). But their capability for taking risk is highly variable. Moreover, these organizations face political scrutiny, particularly in Europe and the USA. Such large bodies also struggle with their size, an acute problem when investing in entrepreneurial projects. It is only recently that they have entered finance for later stage funding of medium high risk. An example is Plastic Logic, where the Russian SWF, via its RUSNANO arm, has invested some $700 million to produce a second production line for plastic transistor film in Russia (see Appendix 1). As more developing countries seek to move from being commodity sources (or only manufacturing centres) to innovation centres, especially for commercialization of innovation with high capital demands over the long term such investments may expand greatly, as they hold the promise of high tech industries growing up locally. It is a natural way to develop the fruits of high cash flow as a local industry development.

Public finance

Through the case studies we have seen in the examples from Germany (e.g. DLR Space Centre and KUKA) and Sweden (VINNOVA and Robotdalen) that there are various forms of national and local government support which successfully offer this kind of 'long-term capital' funding. Note that support may be offered either in finance or in intellectual capital by transfer of IPR. An example of the former is government supported long-term R&D in Sweden through the VC type operation, VINNOVA, in robotics for Robotdalen. An example of IPR transfer includes R&D offered by government centres of excellence (such as DLR in robotics). However note that these piecemeal examples of support at a national level in specific sub-sectors are not replicated across Europe. In consequence, a highly variable set of measures exists today, individual to each Member State

In our case studies, the iRobot Corporation (see case study in Appendix 1) was a significant recipient of support from the Small Business Investment in Research (SBIR) programme administered by the DoD, DoE, NIH, NSF and other agencies. Under the SBIR companies can receive grants for feasibility assessment (Phase I) and for Phase II (prototype). Since innovation in robotics falls under the DoD, iRobot could (TBC) also benefit from procurement of the R&D product in Phase III by the DoD. Procurement by the other agencies (DOE, NIH and NSF) and the SBIR design as well as the question whether such schemes are appropriate for the EU is explored in detail in a parallel study.

Intellectual capital

In many of the companies studied, intellectual property issues were important in different ways and to different degrees for each sub-sector. They were a significant factor for the display start-ups and innovators – CDT, Plastic Logic and E-Ink (as well as for Kodak) in their early innovation through start up and establishment. Patents have been important in robotics, but so has open intellectual capital. It is only over the past decade that IPR questions have become a paramount factor in the ICT industry generally, for Apple, for instance, and far more recently in web services, e.g. for Google. Here the protection of IPR through patents has allowed Apple to defend its position against newcomers attempting to enter some of its markets (e.g. smart phones and tablets).

IPR has now become a key competitive weapon in the USA in ICTs. The battle with rivals is no longer fought out only in the marketplace but also in the courts. Therefore, as competitive advantage comes from holding patents, especially in the USA, the sums being paid to acquire them have increased enormously. The competitive advantage from holding patents is behind Google's purchase of portfolios of patents from IBM, twice in 2011 and also the $12 billion acquisition of Motorola Mobility. Gradually these IPR battles are seeping worldwide, with court orders to stop product sales in the EU (Netherlands and Germany) becoming common, e.g. Apple aggressively prosecuting its own supplier, Samsung, over tablet design.

Registered existing patents held by others, especially if formed into apparently impassable 'patent thickets' (Shapiro, 2001), are highly relevant to the small entrant innovator, not just in terms of its own innovation per se but in terms of the menace to any creative efforts from those patents. A threat of legal action over infringement of existing patents that might possibly overlap, acts as a strong inhibition to fresh exploration of a technology. VCs will tend to view any new venture through the lens of potential litigation from patent holders and avoid investment in such cases (see Anton et al, 2006; and Kaplan, 1994). Such threats are effectively unlimited when the patents that potentially overlap are held by the largest ICT players and 'non-practicing entities' (NPEs) sometimes termed 'patent trolls'. Small companies cannot contemplate the legal costs involved of a process that may take several years, during which investment will be effectively frozen and further work in jeopardy of being found in infringement of a patent, however remotely related. This is especially true for patents granted in the USA, where the types of patents (which include software and business models) and their permitted generality combined with ease of filing make the threat of overlap litigation more probable. In the USA, litigation and the threat of litigation is a real problem: it is likely that fear and uncertainty 'in the shadow of litigation' leads to inefficiencies in how well the market for ideas and the market for entrepreneurs work. A US perspective on the balance for and against litigation (in that it may somehow resolve uncertainty more quickly and more effectively) is given in the FTC's 2011 report on the role of patents, in what it terms the "IP marketplace" (FTC, 2011).

The views of some, especially in the USA, are that these risks of inefficiencies due to the threats of litigation are balanced by the importance of recognisable incentives for innovators. This rationale holds that without a clear path to enable entrepreneurs to profit from invention, innovators are less likely to expend the necessary effort. However, patents do not always provide such a path, and in ICT they tend to provide that path less often. Even so, many of the larger ICT firms in the USA continue to consider patents to be important to competitive advantage, to compete and grow (Graham, 2009).

The gap between the USA and the EU here could be more advantageous to Europe, despite the fact that a full common EU patent is yet to appear. Obtaining a patent in the EU, with more due diligence and a higher threshold on uniqueness and validity, is more costly, difficult and time consuming. Consequently patents are used differently so their potential to limit innovation in the ICT industry is more limited than the litigious US IPR arena. Also with the inadmissibility of patents on software, business models or processes, the field for innovators appears more open and less threatened by commercial risks of litigation in the EU than in the USA. In general, the quality of patents is connected with their cost – greater proof of originality requires greater professional research and thus expense, but how this should be spent, for instance, on a more searching judicial inquiry into validity (e.g. see Lemley, 2001) is open to question.

There are alternatives, however. One model for generating intellectual capital in ICTs has been around for the past 25 years in collective development of intellectual capital. It substitutes trust and co-operation for competition over every morsel of IPR. The traditional route to innovation and its intellectual capital implies that a company innovates on its own. In contrast is the 'open innovation' concept of employing the collection and use of external knowledge. Many ICT companies now share knowledge for large-scale open innovation. The two leading open innovation structures are patent pools (Shapiro, 2001) and open source, which have different functions, applications, levels and modes of use. However, each has specific issues of financial and non-financial costs and benefits, suitability, levels of cooperation, problems, risks and feasibility (Rayna and Striukova, 2010).

The use of open sources in technology or software has a major impact on innovation as they reduce the cost of entry to a business, as seen in the robotics cases and in web services. Moreover they have increasing returns with volume across a whole sector if many enterprises can benefit from them, since a basic cost is removed. So there are leverage effects, of creating the asset once (be it software or designs or other IPR) realized across the many enterprises who exploit that asset (and again leverage) for their own production.

A general movement among innovative ICT firms is to shift to an open innovation model and use a greater variety of external sources to create new innovations and sustain existing ones across all industries (Dodgson, 2006) and recently this has taken new directions in 'open source goods' to solve the problems of product complexity (Wei and Wei, 2011). Note that the whole web services subsector came into being and is still based on open source software – for the World Wide Web, the internet communications and management protocols and the majority of web server operating systems (Forge, 2004). There are also many examples of how open innovation principles are applied in the ICT industries, such as consumer electronics (Christensen et al, 2005). Open innovation is not just an alternative, in that it can work together with proprietary IP and patents in ICT, especially as proprietary IP may often build on open IP. This may be explicitly permitted, for instance with open source software licences of the UNIX BSD type. A major example is Apple's iOS and MacOS which are based on developments from an open source operating system from Carnegie Mellon University, Mach 3.0.

Note that where there are grey areas in the uses of IPR for web services and their related devices (as in the web service provider verticalization model -see Appendix on business models) then major disputes are increasingly common between the dominant players, aiming at large long-term financial gains through the courts rather than the markets. This is the case in the Oracle plea against Google in April/May 2012 over the use of the Java language to write APIs for the Android operating system.[21]

Patent pools may be used where a standard complex technology is being assembled and all the contributing IPR from different companies can be pooled as a common set of patents. Then others pay standard 'reasonable' royalties to use the pool. This is especially useful for ICTs governed by standards such as cellular mobile and image processing, with the MPEG series. As patent pool participants have to make a tangible contribution, a certain amount of pre-existing research and development is required, so returns on investment in patent pools may be fairly certain. It should be noted that patent pools are not a panacea, but instead bring their own set of problems. This is highlighted by Regibeau and Rockett (2011) and also by the 2012 conference on transparency and predictability of licensing in ICT through patent pools (European Commission, 2012).

The dangers come when one player with key patents withdraws them, or offers less valuable or irrelevant patents to claim disproportionate royalties, all of which requires adequate contracts to set up and then monitor. Contributors gain from participating if their share of the pool royalties is higher than the royalties they would have obtained when licensing their patents individually, although the value of patents is essentially unknown. Moreover, for standards-based technologies, the standard may be restricted to include only pooled patents. Patents outside the pool become

[21] Java is owned by Oracle, and its open source status has always been in a grey, relatively undefined area. The use of a programming language to create the APIs has been considered 'fair use' in the past. Moreover the knowledge of how APIs work is essential for the ICT industry to build compatible software modules – for instance the PC industry could not have been created without it, yet is could be argued that this is proprietary knowledge (Waters, 2012).

proprietary technology. Note that there is also a risk of the patent pool being declared illegal, if antitrust authorities determine that nonessential patents are in this pool and its is a way of colluding to control a market by restricting competition.

For the start-up SME, patent pools could be most useful, if the collection of patents is accessible by outside parties and not just by the contributors of its patents who form the pool. The latter tend to be the established large companies, mutually benefiting from sharing each other's patents. A common situation for a small company (especially a start-up) is that it cannot hold a ticket to entry, as it has too few or no patents to contribute, but instead it could perhaps benefit from licensing the pool. It would then obtain a portfolio of IPR to new technology to cut its costs of R&D and patenting, while lowering the resources expended to negotiate with multiple licensors and it may even ensure compliance with coming standards, if the pool becomes the basis for international standards (e.g. as for 3G mobile with UMTS). However this assumes that the access to the portfolio of patents in the pool is permitted, through external licensing, and also that the licence is affordable for the SME. For example, if the cost is founded on a (low) percentage of royalties on products or services sold which incorporate IP from the patent pool, then it may be viewed as affordable. The alternative could be an upfront fee which might be extraordinarily high for a start-up but 'reasonable' for a large corporate, in terms of competition law for patent pools.

However if a small company *can* participate, the increased appropriability or absorptive capacity, i.e. ability to profit from innovation (Pavitt, 1984) brought by a patent pool may be more advantageous for small companies than for large ones, as it may form a far larger proportion of their income. However, patents owned by small companies may not achieve their potential returns. Much larger companies may perhaps safely ignore an SME's rights to their IP, as SMEs lack the resources to defend their patents in long, uncertain and costly patent infringement litigation. This tends to deter innovation (Rayna and Striukova, 2010). With a patent pool comprising only small firms, there may be some advantage for the SME, as the size of the pool makes it less possible for larger companies to override the IPR, especially if some larger companies also join and with greater resources for legal enforcement procedures.

From our case studies, especially in robotics it is evident that open source IPR is important in innovation, specifically for software and for standard design libraries of structured data. DLR, the German government's space agency involved in robotics makes its design libraries available to all, under open source licences for use in commercial applications. This provides the basis for KUKA's own design libraries. In the USA, Willow Garage, supported by Google, has made open operating systems for robots available, which are used widely in the academic and triple-helix style innovation communities driven by academia.[22]

In contrast to patent pools, which are based on the patent's monopoly of IPR use, open source is based on disclosure and freedom to use the IPR built by a team of collaborators under acceptance by contract of various conditions contained in the open source licence, of which there are many variations in legal constraints (Forge, 2004). Open source projects are collaborative developments (often of software), where the source code as well as any updates are openly available to its users and creators. Although most related to the software industry, in theory open source can be employed to share original IPR in any sector.[23]

By using open source software, in accordance with the open source licence, the SME gains significant protection from infringements on proprietary software, ideas and copyrights, as the source code and thus its concepts are openly available to all. Note that the freedoms and limits vary with the licence – the BSD[24] Unix type of licence is the most open – permitting any use of any part of the code for commercial purposes, without requirements for posting any open new improvements or additions to the original open source library (as for instance the GNU licence requires). Perhaps it is for this reason that three of the most important operating systems in the world are, in their fundamentals, based on open source injections of IPR – from various versions of the Unix operating system. These are Apple's iOS (whose origins lie in Steve Jobs' NeXT NeXTSTEP operating system, based on the MACH kernel from Carnegie Mellon University, with FreeBSD source code extensions), Linux, and Google's Android. We may expect this importance will be amplified over the coming decades as all three figure in tomorrow's ICT world of mobile devices, while their only rival, Microsoft's proprietary Windows, has a comparatively minor market share today in mobile and its future here is still unclear.

[22] The European Commission's "Interchange of Data between Public Administrations" Programme (IDA) in 2002 financed an independent study on the opportunity of making software specific to the public administrations available for re-use, by creating a "place" where to pool all software given by administrations, after OSS was perceived by the EC as both a great opportunity and an important resource for the EU development, as mentioned by Erkki Liikanen, Commissioner for Enterprise and Information Society, in 1999, when the EC opinion was that *"by focusing on open software standards (….) it may be possible to spark European creativity in this area and dramatically reduce our reliance on imports"* (ISTAG, 1999).

[23] Recent work shows how "econometric estimates indicate that entrepreneurial ventures collaborating with the OSS community exhibit superior innovation performance compared with their non-collaborating peer" (Piva, Rentocchini and Rossi-Lamastra, 2012), therefore indicating that collaborations with the OSS community should exert a positive effect on entrepreneurial ventures' innovation performance.

[24] Berkeley Software Distribution – a free open source licensed version of the Unix operating system from the Regents of the University of California at Berkeley.

In the market, OSS is highly significant as a balance. The commercial software industry is dominated by the positive feedback effects of the power of increasing returns – as sales volume mounts the seller gains market power to obtain more power in the market and so more leverage to squeeze out rivals. Over the past 20 years in the USA, this kind of market behaviour has been tolerated in software markets in ways that were not in earlier eras in sectors such as energy and rail by antitrust laws. Software escaped notice because, early on, courts were persuaded that they could not rule, first, because they did not understand software and its conflicts. Second, the legislature did not intervene as software was seen as a peripheral product, not central to an economy, and so was an esoteric subject on which to rule. Only over the last decade, led by the European Commission in its landmark rulings against Microsoft,[25] has this changed, and fairly significantly.

Today this is no longer the case as it is increasingly recognized that software is at the heart of the modern economy based on high technology and knowledge work. This dependence will grow dramatically. In the next decade, many countries will move to absolute dependence on software in all major sectors of employment and economic prosperity, from health to banking to steelmaking.

OSS becomes increasingly important as means to balance the market power of proprietary software suppliers. Proprietary power is being increased, protected in the cloth of legality over IPR, to build increasingly wide *de facto* standards in the software market. For instance, some years ago, Microsoft added a browser and a media player and so cut out the market for these as separate products. OSS balances moves to *de facto* standards and monopoly pricing by:

- First, restoring complete choice to the users, and
- second, ensuring open interworking as all interfaces are freely published in the public domain.

OSS acts as a necessary rebalancing of market powers, and in some cases, one of the most important sources of innovation.

The role of government in relation to collaborative innovation is one of encouragement, not only through appropriate competition laws which permit shared patent pools at ‘reasonable’ costs[26] to potential innovators but also in endorsing open source. The latter action may be through

[25] The rulings against Microsoft on bundling and commercial practices of a decade ago are revisited in the May 2012 letter from the Competition Commissioner, Mr Almunia, to Google on abuse of its significant market power, in search related practices (Alex Barker, 2012, *Google told to change or face fines*, Financial Times, 22May 2012) prior to a potential charge sheet.

[26] What is reasonable requires competition authorities to become involved to ensure patents are not used ‘to hold industry to ransom’ by extortionate royalties as has happened in various ICT sub-sectors using patent IPR in public standards.

procurement of ICT products and services having open source licences. This can reduces costs and increase security, especially for software for common utilities and applications, such as operating systems, web servers, databases and office systems.

Note that the role of the European Commission in stimulating research development and innovation, RDI, in joint ventures has taken a new direction in 2012. Its upcoming EU Framework Programme for Research and Innovation, Horizon 2020 for a 2014-2020 time frame, opens a new avenue for scientific, technological and industrial research, development and innovation (RDI) declaring support for new forms of public private partnership (PPP) funding structures. About 40% of the €80 billion budget proposed would be allocated to solving societal challenges. The latter include well-being, health and demographic change, food security and the bio-economy with sustainable agriculture, the environment with clean energy and transport. The objective is to gain a unique global competitive position for Europe in solving the key challenges of our time. This shift could be significant in terms of strategic objectives and thinking of what innovation is about and its main focus. In the programme, societal challenges are not considered as interfering externalities but as starting points (Kulkki, 2012).

Human capital

Many of our case studies highlight the critical importance of human capital in innovation. In some cases the innovation depended on gifted individuals who discovered something completely new that formed the basis for a new company, for instance, as in the case of Google or CDT. Sometimes, entrepreneurs were the driving force harnessing the skills of technicians (e.g. Skype). In most cases, beyond "the discovery" the company required a variety of knowledgeable and skilled people, both technical and managerial, to progress. In the case of Amazon, a large number of people with appropriate skills were needed. While an innovative business needs human capital of these different kinds during its growth, our case studies strongly suggest that it is the most highly skilled individuals who are fundamental to innovation.

In some of our case studies there is a clear connection between successful innovation and the generation of these highly skilled individuals through higher education. At Stanford, Google's founders benefited from a very supportive, nurturing environment, with mentors who were able to protect them and indulge their activities. E Ink, iRobot are other examples where US start-ups depended to a greater or lesser extent on links with excellent higher education institutions – in these cases, MIT. But this is not just a US phenomenon, as there are several European examples in our case studies. For instance, the Institute for Applied Photophysics at the Technical University of Dresden with the Fraunhofer Institute founded Novaled in Germany, and the Cavendish Laboratory at the University of Cambridge spun out both Plastic Logic and CDT.

So how do the EU and US higher education systems compare in this regard?[27] Of the top 50 departments in the world in different subject areas, the majority are found in the USA (39 of 50 in computer science, 33 in engineering, 37 in neuroscience) (Technopolis, 2011; OECD, 2011). The research performance of Europe's universities seems to lag behind that of their US counterparts, particularly in the top 50 universities in the Academic Ranking of World Universities (ARWU), colloquially known as the 'Shanghai ranking' (Aghion et al, 2005; Bruegel, 2008). Care should be taken in interpreting the results of any index since they inevitably contain biases.[28] Moreover, it should be noted that even in the Shanghai ranking, a European 'top' university tends to be among the best 25% in the world in at least one discipline, although the number of disciplines in which it is world leader is on average substantially lower than that calculated for a top US university (Moed, 2006). In other words, while there are centres of elite academic research in the EU, there are just many more in the USA. These centres of excellence may well be the engine of innovation. Moreover, it is around these centres that clusters of innovative companies have formed, such as around MIT, and Stanford.

Clusters

US commitment to elite education, and thus to human capital, is further intensified by the cluster effect of networks of related skills around key academic and research institutions (Bercovitz, et al, 2006). These clusters have been nurtured by the US government in a variety of ways. Case studies of Apple, Google and Robotdalen emphasize the importance of government intervention to form clusters from which the start-up can profit. But there has to be a critical mass of human capital for this process of interchange of people between companies to work. Thus the difference between the USA and the EU is one of time and long-term investment in human capital – people and their networks – the USA began such clustering over 70 years ago for military purposes and so accumulated rich banks of human capital. In contrast, the EU began with government intervention 30 years ago with its 'techno-poles' of Sophia Antipolis, Grenoble, Karlsruhe, Munich, etc.

Clusters are important to the start-up at a materialist level. They offer the two basic resources, a concentration of scarce, highly skilled talent, often highly qualified and ambitious engineers and researchers, and also the key funding for the various stages of start-up, perhaps with the formation of venture capital firms. These two resources host and create anew the intellectual capital that the cluster embodies. Moreover the cluster stays alive through encouraging and nurturing networks to locate each of these three resources. Equally important, at a cultural level clusters spread the

[27] This report does not analyse more generally the differences in the US and EU education systems and the possible impacts on innovation.

[28] A study by Florian (2007) found that the results emerging from the ARWU data were not replicable, calling into question the comparability and methodology of the data used in the ranking.

example of innovation as an admired pursuit, with its acceptance of risk in forming or joining a new start-up concern, as the normally accepted mental model for a successful career. This multiplies the supply of human capital as confidence is gained in this system for work and new funding, even in the event of failure, with increasing numbers of 'serial entrepreneurs' as the cluster matures and grows outwards.

Cultural capital

Mobility

Most typically in Silicon Valley, there is a predominant attitude among the highly skilled and qualified that risks are worth taking if eventually the result is ownership or part ownership in a successful venture. Employment is seen as a transient state, something that may be necessary between entrepreneurial ventures. Thus there is a tradition of workers moving between start-ups, a mechanism which provides both job security and mobility of the skilled workforce, to assure investors that the right skills are easily available. A culture of flexibility and constant change in working conditions is imbued. The case studies of Google, Apple, E Ink, iRobot and Amazon emphasize that moving on to a new company is normal, and most importantly, failure of a start-up may be a useful learning experience.

In the EU on the other hand, failure and renaissance in a new company is not so welcome. In the UK, for example, its SMART programme for R&D support for SMEs is closed to companies whose directors have previously taken funding in an earlier start-up which has failed. In the EU, bankruptcy is commonly associated with fraud and so can leave a trace through the rest of working life, making the search for funding difficult in some Member States. Thus the culture in Europe is very much that risk taking is generally to be avoided.

Risk and entrepreneurship

Government policy could help in shaping the culture, specifically the attitudes to failure, in terms of the laws around bankruptcy but also in terms of not denying support for a new venture when a previous one has failed. This implies that government has to accept that failure is a necessary part of supporting innovation. For a mature company, the culture within the company is the prime factor for successful innovation. Hence *corporate* culture has been identified as perhaps the strongest driver of radical innovation, considered globally, across all nations (Tellis, Prabhu and Chandy, 2008) as a stronger predictor of financial performance than other popular measures (e.g. patents). At a company level, researchers (e.g. Chandy and Tellis, 1998; Olson, Walker and Ruekert, 1995) have identified that the corporate cultural setting can be translated into three company level attitudes, backed by three company level practices to drive innovation. These three company attitudes are:

- the willingness to cannibalize existing products and assets;
- an orientation towards the future; and
- acceptance and tolerance of risks of innovation.

Why are these three attitudes likely to be essential drivers of innovation?

First, the company must be open to new concepts of where profits will be derived from, which will not be the products and services of today if innovation is to occur. Apple is the clearest example of this in our case studies. Note that start-ups have none of this legacy profit stratagems to fight. Second, a firm that is successful in one generation of technology is often blind, owing to its current problems in perfecting today's offering, to the next generation. An example of this is the case study of Kodak in its inability to move to digital imaging from its colour film culture. An orientation towards the future market forces a firm to realize the limitations of current technology and envisage the emergence of the next (Christensen and Bower, 1996). Third, exchanging the safety of today's profits for the risk of innovative development of tomorrow with its unknown profit stream seems to be higher risk than staying still – which may not come naturally to some managers. Thus a company must instil a tolerance of risk (Fiegenbaum and Thomas, 1988; Kuczmarski, 1996). A willingness to abandon the profit stream from today's offerings means being capable of holding an enduring vision of the future, such that the company can enter the next generation of innovation (Chandy and Tellis, 1998; Christensen, 1997).

In the case of start-up companies, since the team is assembling for the first time, the cultural capital consists of the inherited cultures of the environment and the team. This is why a past failure is considered valuable in Silicon Valley. It teaches wisdom in a start-up situation of what to do and who to trust and what mistakes to avoid so that the experience is not repeated. The internal corporate culture is shaped by the prior experience of the key workers and decision takers in the industry, as well as the region and the country. Three related aspects of national culture that can drive innovation have also been identified (Hofstede, 2003): the values of its citizens, geographic location, and a country's main religion. These factors tend to influence conformism, individualism and degrees of consensus, the relative importance of hierarchy and the capability for individual creativity – as well as the rather different capability for group creativity, in which the relation of the individual to the group defines different degrees of motivation. National cultures also have a general influence over the behaviours in the start-up (Trompenaars, 1993).

But perhaps for the start-up, the most important, almost subconscious, cultural factor is the attitude to risk, i.e. whether it is to be accepted or rejected and at what level. In Silicon Valley, and to some extent more generally in the USA, an entrepreneurial attitude is much more common than in Europe.

3.2 The role of government: financial and institutional instruments

What, then, can we conclude about the role of government in the evolution of the companies studied? In general, governments can support innovation in the following ways:

- Regulatory interventions to improve the policy environment for innovation (e.g. in our cases we observed the stigma of bankruptcy, restrictions on mobility by labour laws, and the (mis)use of patents.
- Public funding via financial and institutional instruments. This may take the form of direct funding of research, public procurement or support for clustering, which combines public and private inputs both in funding and in kind. Financial instruments in our cases include tax benefits, grants and loans.[29]

As the examples of CDT and Plastic Logic show, venture capital may be less likely to have the scale in time and magnitude of investment for complex technological innovation which may take decades rather than years to become commercialized, either because the technology or the market is nascent. The policy question is whether there is a rationale, economic or otherwise, for the public sector to subsidize companies developing technologies that require long-term financial support. On the basis of traditional economic theory, it is not always possible to justify subsidizing such companies on the basis of externalities or spillovers. Yet, the theory of increasing returns, espoused by economists such as Arthur, explains why there may be other valid economic reasons for doing so (Arthur, 1994).[30] Increasing returns theory provides the justification for strengthening the research base, encouraging joint ventures, collaborative working, clusters, open standards as well as long-term financial support for complex technologies.

When there is a rationale for public support, the government might provide companies engaged in long-term research and market development with long-term funding or support in kind. Such funding might have no fixed repayment schedule and this can be termed “patient”. Lack of long-term (“patient”) funding is the key quandary of companies which, by their very nature, cannot produce returns for early-stage investors.

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[29] Public funding instruments are discussed in a parallel study. See Audretsch, 2012.

[30] W. Brian Arthur opposed models of simple decreasing returns for high technology industries showing instead how increasing returns may magnify seemingly small, random occurrences in the market place over the long term. Mainstream economics is gradually evolving to incorporate theories from behavioural economics, complexity theory and other strands of economic thought (e.g. see Foldvary, 1996; Anderla, 1997).

However, there is a further argument for public research funding to support the translation of discovery with long-term returns[31] into industrial production. This argument calls for complementing or replacing private funding, which, by its nature, is short term and with a preference for lower risk. This argument deserves some attention, since it is generally true that the public sector has more ability to sustain higher risks and for a longer horizon, when compared to private companies. Public funding of such high risk-long term investments makes sense if the expected social return is higher than the expected social cost, and this requires a careful selection process of the areas/sectors in which public support of technological development is provided.

As already highlighted, in web applications there is little evidence of direct government intervention having an effect. However, there has undoubtedly been an indirect role of government via the "spillovers" of past government investments since the late 1950s – the first customer for Fairchild, the Shockley spin-off company, was the US military. Fairchild sold transistors for the new B-52 bomber's navigation computer, at $200 each, to IBM military research in Owego (Edwards, 2012).

Ten years later Intel would be formed by four of the Fairchild engineers from the original "traitorous eight" who left Shockley and so Silicon Valley's hold over the ICT industry would be cemented. Many major US technology companies, such as Hewlett Packard and Qualcomm started up following support from military contracts, which gave them not just their early procurement but also their R&D funding, from which they were allowed to keep all resulting IPR.

HP is another example: Frederick Terman, an engineering professor at Stanford in 1939, encouraged and backed two gifted students, Bill Hewlett and Dave Packard, to enter a technological niche in high stability electronic oscillators and frequency counters. As Terman observed: "for activities involving a high level of scientific and technological creativity, a location in a centre of brains is more important than a location near markets, raw materials, transportation or factory labour". Thus, due to knowledge spillovers, Silicon Valley was indirectly "subsidized" by US government investments in the electronics of war.

From the case studies it was noted that the small innovative enterprise needs support in moving from an engineering prototype to full production, in a staged manner ('crossing the valley of death'). For instance, start-up iRobot turned to the SBIR because perceived risk was too high for VCs, according to Colin Angle (iRobot, chairman and CEO).

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[31] Edward Benthall, chair of Cambridge Enterprise, notes 'there is no active investor community to take care of a certain kind of company', referring to Plastic Logic and certain life science companies with similar needs, ibid, Startup Intelligence, Regional report, Nov 2011.

The choice of instruments for public funding is critical, as the robotics case study of Robotdalen shows. The lessons of VINNOVA's funding instruments and the Robotdalen case study shows that the use of 'smart capital', i.e. borrowing the idea of using experienced investment managers from the private sector who have managed start-ups, would be invaluable for guidance. The VINNOVA programme, which combines external assessments, professional venture managers and (patient) long-term funding for a much longer term than typical for VC funding or government programmes, may offer a useful way forward.

The German federal state of Saxony provides another example of government support. Founded in 2000 by researchers at the Cavendish Laboratory of Cambridge University in the UK, Plastic Logic now has its R&D centre in Cambridge, with a high-volume, state-of-the-art manufacturing facility in Dresden, Germany and product engineering, sales and marketing and executive management being headquartered in Mountain View, California, USA. Its first manufacturing plant in Europe, in the capital of the federal state of Saxony, Dresden, was sited at the heart of the German electronics industry – sometimes called "Silicon Saxony". Germany and the Saxony region offered significant financial support grants for starting up new high technology research on manufacturing processes and production facilities. Possibly, in the next stage, the new Russian owners will use the know-how to build a second manufacturing plant in another location in Russia or elsewhere where labour costs are for the time being lower than in Germany. Supporting the formation of clusters is an appropriate role for government because a cluster is based on spillovers from one company to another. Cluster formation typically is a lengthy process, the result of building on existing strengths. Clusters typically require long-term investment in human capital – often around a centre of technological excellence, within which there are more specialist centres for deeper research in particular technologies, and we have previously highlighted the examples of MIT's Media Lab, which spawned E Ink, or the Cavendish Laboratory, which produced both CDT and Plastic Logic.

3.3 Summary of lessons from the case studies

In this chapter, we have attempted to distil policy lessons from the case studies in the following areas, which relate to inputs in the innovation process. These are summarized below:

- A key lesson from the experiences of all the subsectors, particularly web applications, is the critical importance of higher education and of local networks in the formation of clusters. At Stanford, Google's founders benefited from a very supportive, nurturing environment, with mentors who were able to protect them and indulge their activities. Case studies of Apple, Google and Robotdalen emphasize the importance of government intervention to form clusters from which the start-up can profit. But there has to be a critical mass of human capital for this process of interchange of people between companies to work. In those particular ICT sectors where US companies seem to excel over the EU, they are often in areas that build on the quality of elite academic research, backed by its pools of human capital. The recommendation that Europe needs greater support for academic and public sector centres of excellence for R&D with commercial applications is supported by the literature.

- The role of government in relation to collaborative innovation is one of encouragement, not only through appropriate competition laws which permit shared patent pools to potential innovators but also in endorsing open source IPR, research results and software. The policy suggestion is that much stronger affirmative action is necessary for public procurement to be oriented to open source software, libraries and common shared intellectual capital (Forge, 2006).
- Internet start-ups are ideal VC investments, as our case studies of Google, Skype and XING show – having relatively low entry costs and low capital intensity. Thus web services such as Facebook, Google, eBay, Twitter, etc are strongly favoured by the VC community. As the examples of CDT and Plastic Logic in the case studies show, however, venture capital may be less likely to have the scale in time and magnitude for complex technologies that require longer-term investment. When VC funding is inappropriate, public funding instruments (such as the US SBIR, now envisaged in the EC's Horizon 2020) can be better suited, as discussed by Audretsch and Aldridge (2013).[32] The choice of instruments for public funding is critical (see the role of the Swedish VINNOVA model in the robotics case study of Robotdalen).
- Government policy could help in shaping a culture more conducive to innovation. In particular, governments could specifically address attitudes to failure, in terms of the laws around bankruptcy, but also in terms of not denying support for a new venture simply because a previous one failed. This implies that government has to accept that failure is a necessary part of supporting innovation.
- The large, unified market in the US has allowed Amazon to bring economies of scale to bear. In contrast, the European market for books is fragmented owing to national or even regional, languages. Since mobility is important as a mechanism which provides both job security and mobility of the skilled workforce, to assure investors that the right skills are easily available, barriers to migration are harmful.
- Another point, perhaps obvious but it bears repeating – innovation is not just about technology. This is most clearly illustrated in the Apple case study. What has distinguished Apple in terms of innovation is not so much its technology but rather the combination of a rewarding user experience and simple but highly effective design with novel business models.

[32] The Development of U.S. Policies Directed at Stimulating Innovation and Entrepreneurship David Audretsch and Taylor Aldridge, 2013, forthcoming JRC-IPTS report.

The case studies analysed show that there are very different factors that proved to be essential for corporate success, so that there is no unique policy intervention that could improve Europe's innovative performance.

First, the EU Member States should make sure that inventions are generated and that the crucial initial steps from invention to innovation are successfully taken. And this calls for excellence in education and strong and active links between knowledge generation and knowledge exploitation (i.e. between universities and firms).

Second, to increase the return to these policies, it is necessary to create a proper innovation friendly environment: low administrative costs, tolerance towards business failure, a friendly business climate, and a large and integrated market (including for venture capital). The Amazon case shows the importance of the business environment, the existence of a single market and efficiency of services. While on some of these aspects it is possible to have some improvements in the short run, for most of them such improvements are likely to come only in the medium to long run.

Finally, the public sector can provide important financial (e.g. SBIR type instruments,[33] which was crucial in the case of iRobot) and non-financial support. As for the latter, cluster generating policies have been shown in several case studies to be important.

[33] Note that Horizon 2020 foresees an SBIR-type instrument.

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Appendix 1: Case Studies – Web Services, Display Technologies and Robotics

A1.1 Web Services

Apple Corporation

Apple Computer was founded in April 1976 in a garage in Los Altos near Cupertino, California, by Steve Wozniak and Steve Jobs, who were 21 at the time, plus Ronald Wayne (who soon left). Start-up capital was US$1300. Its thirst for innovation and with it, the discarding of conventional market and technical wisdom, was apparent from start-up, when it substituted a US$25 microprocessor, the 6502 from MosTek, for the conventional choice at the time, the US$179 Intel 8080, to make a whole computer motherboard for under $700. Following R&D injections from Xerox PARC, over the next 20 years it then developed a series of highly successful small computers with quite conventional operating systems and quite advanced human interfaces to offer ease-of-use for high productivity. Early on Apple developed a strong emphasize on industrial design in functionality, external appearance, expressed through complementary design of software and hardware for ease-of-use. Apple's design emphasis has profited from one of its founder's sojourns, primarily in the media industries - when Jobs moved on to found animation company PIXAR - but also in UNIX operating systems, as Jobs founded NeXT in 1986. Today such innovative design is the key competitive edge in the consumer electronics sub-sector and web services. It has led to the iPod, iPhone and iPad and iTunes and Apple's App Store. Apple has had failures, such as the Newton PDA and Apple TV.

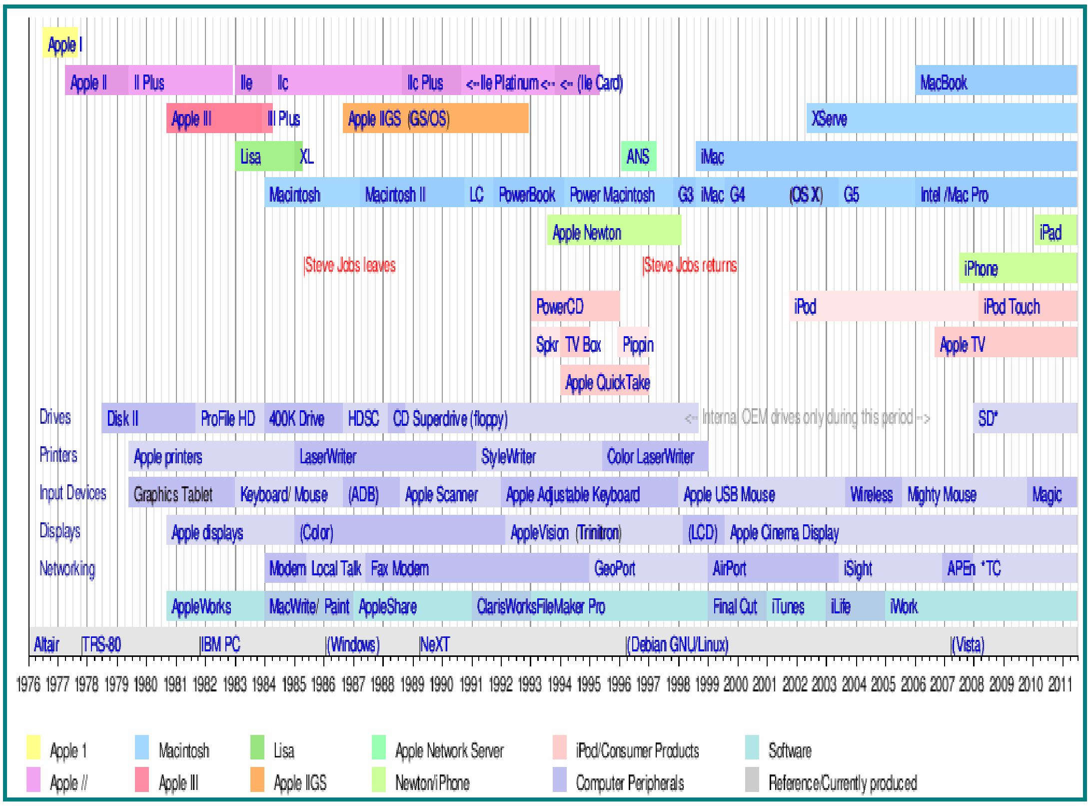
Over the last decade, Apple has changed radically, turning away from pure hardware and software for computing to combining bundles of web services. It exploits its online offerings to complement the new lines in consumer electronics. More specifically, its iTunes web service, for downloadable music tracks with a clever low pricing policy, to match its iPod player and its proprietary download software has revised the music industry. Equally, its smart phone, the iPhone, and its associated Apple Store web service for application ('apps') purchases and download has revised the mobile cellular industry.

This is a most significant change in its own business model. The plunge into Web-based services was been carefully designed to complement the simultaneous move into pure consumer products, with the iPod, and away from pure computing. Thus Apple's major business segments have advanced out of hardware and software products for personal computing and graphics into global retail services, with chains, of both online and physical shops. Its websites for interactive and download services are aimed at a higher-end mass market. The net result is verticalization:

consumer device tied to device content and services that in tandem lock-in the end-user (see the web value chain in Appendix 2). It provides Apple control of every stage of the 'user experience'.

Apple has engineered the success of its Apps Store by not only platforming an eco-system of third party apps developers to produce creative content and applications for consumers, but also by seizing the way in which its content is distributed. Its own websites form the direct distribution mechanism, bypassing content aggregators, content retailers and in the case of content for the iPhone, the mobile operators. Hence, consumers get the content they want with convenient app search, download and payment, while developers receive their fair share of revenue. This follows its vision as expressed by the key founder, Jobs, is to 'make insanely great things' for ordinary people. In the mid-1970s in California there was also the idea that computers would somehow bring freedom to everyone, and so the future was with the personal, and thus small, machines.

In August 2011, Apple Inc., attained the largest market capitalization globally, taking first place from Exxon Mobile, with some US$370 Billion (18 SEP 2011) and advanced in February 2012 to over US$500 Billion, with US$100 Billion in cash assets. In early 2012 it is the largest technology company in the world by revenue and profit, employing 60,000 people. In completely revising its business model, it has shown its abnormal innovative prowess and virtually has leadership in new business models for the web platform and for its hardware and software products. The product range and development history in product terms is shown from 1976 to 2011:-



Source: Apple.

Apple grew at the very first on its own capital, possible at that time when the cost of entry was so small. But at the point of a first larger order, a business angel entered – Mike Markkula. This was the next stage, of really going into production, and passing over the 'valley of death' into full market scale operation, of million dollar orders for volume production with marketing and manufacturing, with its supply chain. From then on, Apple has been self–funded, except after its major losses in 1996/97, when Jobs returned to lead Apple and had to find funding sources from everywhere - even going to rival Gates of Microsoft for several hundred million dollars. Some government contracts have also occurred at critical moments – e.g. sales to local education authorities of tens of thousands of units in mid-1984, following the Macintosh's launch.

Apple's contribution in terms of innovation has often been (but not always) to ignore conventional thinking. It has been excellent at understanding popular demand from the user's viewpoint, not the industry's. So its innovations are far more user-centred than its competition, building a fierce customer loyalty and brand power. This is implemented at a product concept level, not at a feature level as others do. Thus the results of its innovations are about design that uses technology creatively, not just selling technology without deep thought about its use first. This is evident from the 1979 tour that Jobs took of Xerox PARC, shown a technology that let users interact with a workstation via graphics, with windows, icons and pull-down menus (WIMPS) instead of entering complex line commands. Jobs noted that Xerox could have dominated the computer industry. But instead the Xerox 'vision' was limited to building another copier. This emphasizes Jobs' position that different viewers perceive and make decisions and products/services based on their inner vision. This controls the very perception of the limits and extents of an innovation. The vision directs innovation to its ultimate destination in market offerings.

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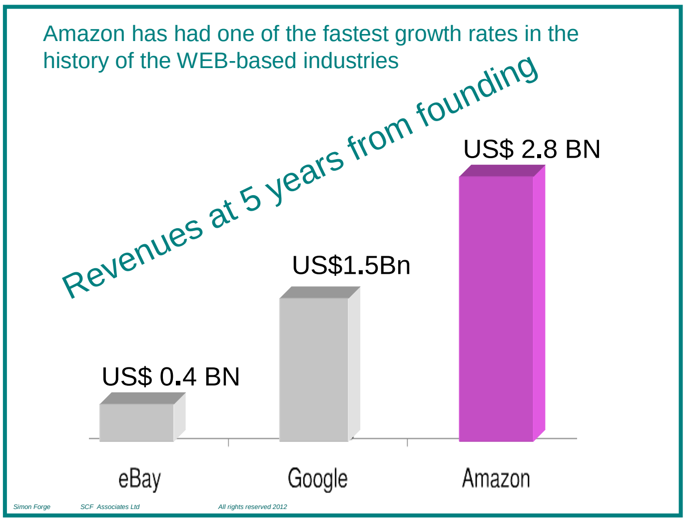
Interview 2011: Mike Nelson, ex IBM VP for internet technology, ex Visiting professor of web and internet impacts and innovation, now with CSC as internet specialist, Washington DC.

Interview 2011: Professor Ajay Bhalla, London, Cass Business School.

Interview 2011: Xavier Dalloz, intermediary between France and Silicon Valley and ICT innovations reporter (also new tablet launcher).

Amazon

Amazon was formed in the first days of the Web, in 1995 in a warehouse in Seattle on the North West coast of the USA. It offered early consumer e-commerce, in books only, using the first 'Mosaic' web browser and its descendents such as Netscape. Its founder, Jeff Bezos, who came from a NY hedge fund background, was crucial to its formation, its business model, early survival, financing and massive success.



In 1994 Jeff Bezos realized that he could create a retail website that would not have the limitations physical businesses encounter: "*You could build a store online that simply could not exist in any other way. You could build a true superstore with exhaustive selection; and customers value selection*."

Amazon grew up in world of book delivery dominated by the publishers and dominant physical distributors, with traditional mail and phone ordering distributors such as Ingrams – the market leader in the USA. The development trajectory has been very fast. It also nearly went bust in its early days. The company first advertised in tiny ads on the front page of the NY Times, before expanding through excellent logistics and order-taking with viral marketing. As the diagram shows (source: company reports) Amazon has had one of the fastest growths in the Internet's history even against eBay and Google. Since then Amazon has become an e-commerce platform for others, based on its pioneering retail e-commerce/ e-shopping business in many product categories, not just books. Since 2007 it has had a successful and logical expansion into e-books with its own into e-readers (the Kindle family) combined with an e-library for charged-for titles for download as in the verticalized business mode for the web services sub-sector (see Appendix 2 for the value chain of this business model). Now it has launched cloud computing services, based on its own business infrastructure to sell to others.

The company first started in Seattle as it was low-cost, with communications giving access to the whole US continent, as well as being a hi-tech cluster. It then expanded overseas in the first five years via acquisition of web-based bookstores in the UK and Germany.[34] The likelihood of its first formation and subsequent success if it had started up in Europe is low compared to the USA due to

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[32] Bookpages, of Slough, UK and ABC Telebuch of Regensburg, Germany.

the lack of single market, both in customers, and in homogeneity of business services across the EU, compared to a single set of business services in the USA - e.g. availability of low cost parcel carriers in competition with the incumbent post office, at the level of the USA.

Amazon's mantra is "detail is delightful" - ever-improving metrics and optimization are its competitive weapons. Before start-up, Bezos carefully assessed the advantages the internet could give him, and pushed them to their limits. Amazon has shaped a quite classical business model with the Internet's specific advantages. It is not that disruptive just: "sell and deliver stuff to customers". Amazon perfectly understands the conventional cocktail of low prices, large selection, convenience and satisfaction from the customer experience. Essentially Jeff Bezos' major concepts are that, firstly going digital enables limitless inventory (by linking to the inventory of supply chain partners); secondly that the web could boost customer care through phone and web call centres (although now this is considered a highly challengeable assertion); and thirdly that web services enable high margin, lowest prices - again quite challengeable.

Amazon's major advantage was its original innovation, selling books over the internet. In getting there first, it grabbed the key position of first-mover. So in the segment where it sits, it is far ahead of competitors like Barnes & Noble who rated their own sales channel of shops as dominant and Amazon of minimal threat –a flea at the most. Today, Barnes & Noble has hit rough seas in the book market and trails Amazon in e-readers with its 'Nook' offering.

Looking under the covers of the business model (see the value chain, Appendix 2) shows that Amazon, despite its apparently virtual presence in cyberspace, is very much a hardware company, needing heavy amounts of capital investment for the two key business processes:

- Its sales interfaces, which rely on some of the world's largest data centres with intensive use of computer hardware and storage, consuming many megawatts of electricity running its order-taking, statistics, sales, cataloguing and customer profiling engines on a base of cloud –computing. For this it has its own hardware manufactured, rather than COTS units.
- Logistics chains of dispatch centres for warehousing and ground transport with a host of delivery services partners. It recruited managers from Wal-Mart to operate its supply and delivery chains – for its Chief Information Officer and its Chief Logistics Officer. They had been responsible for Wal-Mart's secret weapon, a computerized supply chain; Wal-Mart sued Amazon for violation of trade secrets law in 1998.

Consequently, Amazon is adept at reading the market, pursuing customers progressively into new areas, preferring to innovate incrementally while keeping a close eye on the innovations of competitors. Using its data mining and profiling tools, it tries to detect market trends early and then translates those trends and needs into new products and services. Management pays careful attention at the idea/creation stage to what customers are looking for in the products they choose. The goal is to ensure the company is delivering well-differentiated services in line with what the consumer wants. One long-term feature, that has helped Amazon to understand its customers and so become the largest Internet retailer in the world, is the customer review section. It occupies the bottom of most product pages – it was introduced as an early way to harness personal opinions on products, free.

Amazon has entered certain new markets and then sometimes withdrawn as it could manage the processes that inevitably come with a new business model. In 1999 it tried to set up it own auction website, directly in competition with eBay. This was withdrawn as not being successful. Thus expansion has mainly been through selling different products online (the book model) rather than entering new segments like search, auctions or social media (so far!).

Instead it has now expanded into 16 product categories, from the first catalogue of books. They include for example: Amazon-branded electronic products; AmazonFresh sells and delivers groceries in Seattle; AmazonStudios is an online social movie studio; Amazon WarehouseDeals offers discounts on refurbished products. Amazon's Marketplace grew into a highly profitable clearinghouse for used goods. But it has lagged in social networking and social media, leaving Facebook and Zynga as leaders in the area. For its next attack on other web services, it is hiring social media directors and launching into social media and games with software development.

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Google

Google Inc. is an American multinational public corporation, headquartered in Mountain View, CA. It provides internet search and advertising services, as well as a plethora of online tools and platforms including: Gmail, Maps and YouTube. Most of its Web-based products are free, funded by Google's highly integrated online advertising platforms AdWords and AdSense.

Google was founded in Menlo Park, CA in 1998 by Larry Page and Sergey Brin while they were PhD candidates in computer science at Stanford University. In 2006, the company moved to its current headquarters in Mountain View, California. The company's mission statement from the outset was "to organize the world's information and make it universally accessible and useful".[35] The company has a well-known unofficial slogan – "Don't be evil".[36]

Google's growth since its launch has been phenomenal, with annual revenue growing to almost $30 billion in a little over 10 years. 96% of revenue comes from advertising, is still growing It is now valued at $190 billion. It is the most successful company of the internet age.

Initial innovation and start-up

While conventional search engines ranked results by counting how many times the search terms appeared on the page, Larry Page's PhD research focused on analysing the relationships between websites, an approach akin to citation analysis, whereby a website's relevance was determined by the number of pages, and the importance of those pages, that linked back to the original site. Page and Brin's new search engine was initially called BackRub, because the system checked backlinks to estimate the importance of a site, but was renamed PageRank and then Google. In 2001, Google was granted a patent describing its PageRank mechanism. The patent was officially assigned to Stanford University with Lawrence Page as the inventor.

Initially Google was very much an intellectual, scientific, Utopian endeavour. Without doubt both Page and Brin were outstanding computer scientists but, beyond that, their most notable characteristic was their overwhelming self-belief –as Barry Diller put it, they were "wildly self-possessed".[37] While Page and Brin knew they had a unique search engine, initially they had no business plan that would monetize their innovation. Indeed, they were so uncertain about whether to pursue the idea that they tried to sell it to rivals in early 1999, because they thought it was too much of a distraction to their studies. They offered to sell it to Alta Vista, Yahoo and Excite for $1m – they turned it down.

Google's success seems contradictory, the curious result of its founders' unstinting belief in pursuing what they thought was right rather than the pursuit of commercial success. Initially there was no business plan because they were predominantly interested in building a better search engine unsullied by commercial consideration. Page and Brin eschewed the straightforward commercial approach of other search engines that traded higher ranking for payment; this was

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35 http://www.google.com/about/corporate/company/

36 http://investor.google.com/corporate/code-of-conduct.html

37 CEO, InterActiveCorp. See Auletta, p.53.

anathema to Page and Brin, who wanted their search engine to produce the most relevant search results to a query. What they understood early on was what mattered most was users.

Although they did not know how to monetize it, their approach meant they did not follow the route of companies like Yahoo and Excite that sought to be portals for a variety of content. Google wanted to get users off their site to where they wanted to go as soon as possible. Better search was of less interest to Yahoo and Excite because they wanted users to stay on their site for as long as possible so they could sell banner advertising. Page and Brin were opposed to advertising because they had a purist view of the world.[38] And unlike AOL, Google did not have revenue from subscribers.

The commercialization breakthrough for Google came when it found a way to monetize search. AdWords gave it a way of auctioning advertising slots on the search page, favouring firms offering the highest bid price and high benefits to users. Page and Brin were vehemently opposed to advertising-funded search and resisted any move in that direction. They maintained the uncluttered page design and in order to increase speed, advertisements were solely text-based. Keywords were sold based on a combination of price bids and click-throughs, with bidding starting at five cents per click.

Google has continued to innovate or acquire a wide range of software products. It offers online productivity software, such as its Gmail email service, and social networking tools, including Orkut and, more recently, Google Buzz and Google+. Other applications include its web browser Google Chrome, the Picasa photo organization and editing software, and the Google Talk instant messaging application. Google leads the development of the Android mobile operating system, as well as the new Google Chrome OS. In August 2011, it acquired Motorola mobility for $11.5 billion.

Despite this activity, some analysts believe that as the company has got bigger so quickly it is finding it difficult to maintain its success.[39] Google has famously insisted that its employees be allowed to spend 20% of their time working on projects other than their core work (Innovation Time Out – ITO). This has led to some notable successes, e.g. Gmail, Google News, AdSense and Orkut. But the policy of letting a thousand flowers bloom has also been difficult to manage, and also has led to some mediocre products that have relied on the marketing power of the Google brand.[40]

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38 According to Ram Shiram (see Auletta, p.53).

39 "Unleashing Google norms, running the "rapid innovation" engine", http://nbry.wordpress.com/2011/07/26/unleashing-google-norms-running-the-rapid-innovation-engine/

40 http://smartstorming-blog.com/googles-8020-formula-it-can-work-for-you/; http://blogs.reuters.com/mediafile/2011/10/20/sergey%E2%80%99s-secret-google-projects-and-the-challenge-of-1000-blooming-flowers/

Capital investment

Google received about $1miilion in angel investment around the time it incorporated in September 1998, from Andy Bechtolsheim (co-founder of Sun Microsystems) Ram Shiram (ex Netscape), David Cheriton (Stanford computer science Professor), and Jeff Bezos[41] (Amazon). In June 1999, a $25 million round of funding was announced, with major investors including the venture capital firms Kleiner Perkins Caufield & Byers and Sequoia Capital.

Google's initial public offering (IPO) took place five years later in August 2004. At that time Larry Page, Sergey Brin, and Eric Schmidt[42] agreed to work together at Google for twenty years, until the year 2024.[43] The sale of $1.67 billion in shares gave Google a market capitalization of more than $23 billion. The vast majority of the 271 million shares remained under the control of Google. Many of the Google's original employees became instant paper millionaires.

IPR was of great concern to Page and Brin and BackRub was kept under a cloak of secrecy. Page was a huge admirer of Tesla and he was well aware that Tesla had carelessly shared his inventions with others. Consequently the algorithms behind PageRank were guarded zealously. However, as PhD research students, they were expected to present their work and so a paper was eventually prepared and delivered in January 1998.[44]

Location: The company's location was very much determined by the location of Stanford University. In its very early days, Google operated out of the living room of the graduate housing apartment Brin shared in Escondido Village. The Google computers and server were stored in Page's graduate residence. Stanford University seem to have extended considerable tolerance to Page and Brin, turning a blind eye to them acquiring computing resources. According to Battelle, "At one point, the BackRub crawler consumed nearly half of Stanford's entire network bandwidth, an extraordinary fact considering that Stanford was one of the best-networked institutions on the planet. And in the fall of 1996 the project would regularly bring down Stanford's Internet connection."[45] It is hard to imagine a European university providing such a level of support to a couple of renegade PhD students, no matter how innovative they might be.

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[41] Bezos was interested less in the idea and not in the business plan – "There was no business plan" – but rather in Page and Brin "I just fell in love with Larry and Sergey (Auletta, p 44).

[42] From 2001-2011, Schmidt served as Google's CEO; he is now Executive Chairman. Prior to joining Google, he was the chairman and CEO of Novell and chief technology officer at Sun Microsystems.

[43] http://money.cnn.com/2008/01/18/news/companies/google.fortune/index.htm

[44] Page, Lawrence and Brin, Sergey and Motwani, Rajeev and Winograd, Terry (1999) *The PageRank Citation Ranking: Bringing Order to the Web*. Technical Report. Stanford InfoLab.

[45] John Batelle, "The birth of Google", *Wired*, August 2005, http://www.wired.com/wired/archive/13.08/battelle.html

Human capital: In Larry Page and Sergey Brin, there was an unusual combination of intellectual excellence and extreme self-possession. The role of Terry Winograd as Larry page's mentor should also be mentioned. They had a strict hiring policy – only hire the best and people who will fit in. Page and Brin were notoriously choosy about who they allowed to join as a partner or as employees. In the early days, interviews for new staff were protracted and could go on for many months. There was an acid test – the airplane test – that asked "how would you feel if you were stuck next to this person on a plane for several hours?" This is somewhat flippant and was not as important as attention to SAT scores and degrees from the best colleges – as you would expect, they took a scientific approach and relied on data to hire who they thought were the best people by objective criteria. It is acknowledged that, around the time of its incorporation and first few years of growth, Google benefitted enormously from the pool of talented computer scientists and other Silicon Valley engineers because of the dot.com crash and failure of other firms. Google was able to take its pick from the best of the talented people around.

Famously, the hiring of a CEO was protracted and troublesome. The VCs who invested in Google thought that Page and Brin needed proper and experienced business leadership; Page and Brin agreed so they could get the investment but really didn't want a business executive to run Google – they thought of them as bureaucrats rather than engineers and entrepreneurs. Eventually Erik Schmidt was accepted as someone who had both technical prowess and also someone they could work with.

The environment: Stanford University and research funding and the support of the university and the access to Silicon Valley high tech/angel investor/VC network.

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Skype

Skype is a software application that allows users to make voice and video calls and chat over the internet. Skype was founded in 2003 by two Scandinavian entrepreneurs, Niklas Zennström and

Janus Friis, and officially headquartered in Luxembourg. Skype was acquired by eBay in September 2005 for $3.1 billion, but relations between the founders and eBay soured as growth targets were missed. A 70% stake was acquired by an investment group led by Silver Lake (including the original founders) in November 2009, valuing the company at about $2.75 billion. In October 2011 the sale of Skype to Microsoft Corp was completed for $8.5 billion.[46]

VOIP (voice-over-Internet protocol) has redefined the way telephone calls are made. VOIP calls are made over the internet, using the same underlying transport technology that a Web browser uses. Zennström and Friis identified the opportunity and created a business model in which the basic service is free. Skype users can use their computer to call other Skype users for free anywhere in the world, since the marginal cost of a call on the internet is negligible. In contrast, traditionally a call over the public switched telephony network was determined by the distance of a call. VOIP brings about the "death of distance".

The Skype software was originally developed by three Estonian programmers, Ahti Heinla, Priit Kasesalu and Jaan Tallinn, working for a small codeshop, BlueMoon Interactive, the same team behind the controversial file-sharing service, Kazaa. Unlike other VoIP services, Skype is a peer-to-peer system rather than a client–server system, and makes use of background processing on computers running Skype software; the original name proposed – Sky peer-to-peer – reflects this.

Skype became the global leader in internet voice communications, with more than 309 million registered users within five years of launch. During 2010, Skype users made 207 billion minutes of voice and video calls. In the fourth quarter of 2010, video calls accounted for about 42% of all Skype-to-Skype minutes, and in 2010, users sent over 176 million SMS text messages through Skype. 'While Skype is not a phone company, they are by far the largest provider of cross-border voice communications,' says TeleGeography analyst Stephan Beckert.

Skype has shown steady revenue growth since its launch reaching $860 billion in 2010 and likely to be over $1 billion in 2011. It has yet to make a profit. This undoubtedly led to eBay becoming disenchanted with Skype's performance and the seeming failure of synergies to emerge with eBay and its other big acquisition, online payment system, PayPal.

History and development

The basis for the start-up of Skype was the coming together of the entrepreneurial skills of Zennström and Friis and the technological innovation of the Estonian programmers spotted by

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[46] Detailed "infographics" summarizing Skype from conception are available here: http://toddcarothers.com/2011/05/skype-from-conception-to-acquisition-infographic; or http://www.smartfatblogger.in/2011/06/skype-coming-of-age-story-infographic.html

Zennström and Friis. The Estonians were at the forefront of innovation in peer-to-peer software development, using the FastTrack protocol licensed by Joltid Ltd (and owned by Zennström and Friis).

In 2003, Bessemer Venture Partners led the A round financing at Skype. Bessemer, the oldest venture capital practice in the United States invested $1 to $2 million in August 2003. A second investment round in March 2004, led by venture capital firms Draper Fisher Jurvetson and Index Ventures, resulted in $18.8 million in new funding to expand global operations and enhance its consumer offering.[47]

So even though Skype was located in Europe and the entrepreneurial impetus and the engineering innovation were found there, the early stage funding came from Silicon Valley. Looking back on the start up of Skype, Zennström said he started his new venture capital business Atomico because the venture capital market outside of Silicon Valley lags when it comes to funding innovative technologies. As he saw from his own days as an entrepreneur, "In Europe, none of the venture capitalists had entrepreneurial backgrounds. They came from banking or management consulting," he explained. It took forever to get funding at a time when "everyone was still suffering from the dot.com crash," Zennström recalled. "Everyone was still licking their wounds and were very resistant to investing in technology companies."[48]

The period between 2005 and end of 2007 was tumultuous phase with conflict between the founders and the eBay threatening to completely destabilize the company. Following the departure of Zennström and Friis, stability was restored by Josh Silverman as CEO. Under Silverman's two and a half year tenure, the company focused its product efforts around video calling, ubiquity (gaining high penetration on smart phones, PCs, TVs, and consumer-electronic devices), building tailored offerings for enterprise customers, and diversifying revenue through subscriptions, premium accounts and advertising.

Meanwhile eBay was preparing to float Skype via an IPO but Zennström and Friis were not done. They had retained the software patents for the technology Skype used through a company called Joltid Ltd and threatened to cease licensing the technology to Skype. Eventually the dispute was settled with Skype acquiring the patents in exchange for Zennström and Friis joining the Skype investor group with 14% ownership. eBay then sold 70% of Skype to the investor Group led by Silver Lake.

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[47] http://www.prnewswire.co.uk/cgi/news/release?id=119130

[48] "European High-Tech Startups Thrive, Says Skype Founder", *Stanford Business Magazine Online*, March 2011, http://www.gsb.stanford.edu/news/headlines/zennstrom_europe_2011.html

In May 2011, Microsoft Corporation agreed to acquire Skype Communications for $8.5 billion. The deal was officially completed in October 2011 with Skype incorporated as a division of Microsoft, and Microsoft acquiring all of the company's technologies, including Skype, with the purchase. As a result of this deal, Zennström and Friis received $1.19 billion, other investors led by Silver Lake received $4.76 billion, and eBay got most of its money back in recouping $2.55 billion. In essence Microsoft paid about $1000 per subscriber, which some have questioned as being excessive.[49] It is being seen as a defensive move by Microsoft to avoid Skype falling into the hands of Google, a development that would also have troubled Facebook. Both Google and Facebook were reported to have been in talks to buy Skype.[50] The battle over the coming years for the VOIP market will be between Skype in the hands of Microsoft and Google Talk, Apple Facetime and Facebook Chat.

Skype had a network of locations from the outset, with offices in Luxembourg, London, Stockholm, Tallinn, Tartu, Prague and Palo Alto. Although Skype was headquartered in Luxembourg, the founders probably spent as much time in their London and Palo Alto offices. Skype's largest office has always been in Estonia. This was because of the original location of the key engineering personnel – Jaan Tallinn, Ahti Heinla, Priit Kasesalu, Toivo Annus.

On the one hand, the importance of Estonia to Skype seems accidental but it has a reputation of being small, efficient and open to innovative ideas. There is no doubt that Skype has become a kind of role model in Estonia and for other newly industrializing European states.[51] Skype has directly affected the innovative capacity of Estonia which is now host to experienced, networked and funded talent. Former Skype personnel have founded tens of companies, primarily related to Internet services, some of which been successful. For instance, Mikael Suvi made millions developing games for the iPhone. He felt that working for Skype had become too routine.

Martin Goroško, head of marketing for the Tallin Tehnopol technology park, says that Skype has had a bigger influence on young entrepreneurs than the Tallinn University of Technology and the University of Tartu put together. "Eighty percent of the business ideas that reach our incubator or the general community of start-up companies are from Skype," he says.

As already highlighted, there were two key relevant human capital aspects. First the entrepreneurial creativity and risk was provided by Scandinavians, Niklas Zennström and Janus Friis. The key technical personnel were software engineers from Estonia, and this led to the main engineering

49 http://www.bbc.co.uk/news/mobile/business-13343600
50 http://www.huffingtonpost.com/2011/05/10/microsoft-skype-deal-facebook_n_860227.html
51 Toivo Tänavsuu, "ANALYSIS: Skype has turned tiny Estonia into a hub of new Mark Zuckerbergs and Bill Gates's", test★market, 7 January 2011, http://www.testmarket.eu/2011/01/analysis-skype-has-turned-tiny-estonia-into-a-hub-of-new-mark-zuckerbergs-and-bill-gatess/

location being sited in Tallinn. Tallinn was also a centre for other computer programmers and software engineers which provided a source of skilled staff for Skype.

Luxembourg was an attractive location for the official headquarters,[52] mainly because it offered a range of public aids for business and investment such as:

- Investment tax credits of 10% of the acquisition value of investments
- New business tax credits- a 25% exemption on corporate income tax and municipal business tax for 8 years
- Venture capital certificates, up to 30% exemption on profits
- SME incentives up to 10% of costs incurred on investments and reorganization operations
- Regional and national incentives, incentives between 17.5% and 25% of the costs of reorganization in certain regions are available.
- R&D incentives – the government may grant incentives between 25% and 100% of related costs.

According to Scott Durchslag,[53] COO in 2009, "Our corporate headquarters has always been located in Luxembourg for several reasons. There was early interest from investors to invest in an EU-based company. In addition, the tax and legal environment is clear and consistent and the government has a very pragmatic approach to business. The other important factor is that the location enables excellent access to Europe."

Could Skype have started in the USA rather than Europe? It is conceivable and one should recognize that most of the funding came from the USA. However, for once, a curious blend of factors came together in Europe. Estonian IT analyst, Toivo Tänavsuu, summarizes the success of Skype in this way: "The company founders, Niklas Zennström and Janus Friis, bid adieu to salaried work and dove headlong into enterprise. Through their London head office, they used Luxembourg tax breaks and Estonian technology competence, obtained a bit of funding from investors in Silicon Valley and launched a service that has managed to garner 15% of the world's international call market."

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http://www.crunchbase.com/person/niklas-zennstrom

http://www.crunchbase.com/company/skype

XING AG

XING AG is a German business social networking company. It offers a localized social networking defined by language for the business community by subscription. The first launch was in German, across the German-speaking pale, for members in Austria and Switzerland, as well as Germany, under the name, of Open BC, (OpenBusiness Club AG). The company was founded in 2003 and launched in 2004, reaching 5mn members by 2008; in comparison, its US competitor, LinkedIn, had 20m at that time. Headquarters are in Hamburg, Germany and it has 420 employees worldwide. Its revenues from its services announced 29 February 2012 rose by 22% over the 2010 results, to €66.2 million. However, on 29 February 2012 XING announced a one-time €14.4 million write-down on its Spanish and Turkish businesses and declared it would focus on its German-speaking businesses only. As a result, the operating result (EBITDA) which grew by 33% to €22M but with a write-down and taxes yielded €10.2million net income. XING also declared its first dividend, of €0.56/share. The company is thus quite profitable, reflected in the share price of over €40 and its capitalization value of €248.31m (Financial Times, 09 Mar 2012).

XING is the leading professional network in the German speaking communities. A typical member is not a senior executive but a middle manager. As stated in its annual report, XING has over 10 million members registered on its platform, with members in Spain and Turkey. The company provides its members with a range of networking services such as making new contacts, maintaining existing contacts, extending operations into new markets, with jobs search, business organizational tools, exchanges of opinions and information, etc. It offers the Strategic News Service (SNS) in English. The web service is favoured by its membership for two main reasons - to do business and to promote careers. XING is also the leading European network for business contacts in certain other local languages, now numbering 16 altogether. Around the world every day, over 7 million business professionals use XING, the majority being German.

Its main innovation factor is a business model closely matched to its specific target market segment. It has enabled XING to evolve from a business networking platform into the web interface for a widening range of services, for business professionals around the world, of which a growing minority are direct subscribers. The company's business model is not to be mainstream but to cater for local languages for middle management professionals who network in that language. Its aim is also to be more than a directory of business contacts. XING's 'mission' is to make its professional network an active part of every member's life, enabling members to discover professional people, opportunities and privileges through its discovery capability and contact management tools. It is thus diversifying in focussed way into its adjacent market segments. As its CEO Stefan Selbeck noted, at end H1 2011:-

> *"The H1/2011 results show that our strategy of tapping into new sources of income is paying off here at XING AG as they now make up about a third of our revenues. We consolidated our position as German market leader for social recruiting where we acquired more than 800 new customers. On top of that, we also succeeded in growing our member base. XING intends to continue its growth course as there is still a great deal of potential in the German-speaking market." (XING PR, 2011)*

Note that German privacy laws are quite clear that the kinds of things Facebook does may not be acceptable there, or elsewhere in the EU in some MS. German social networking sites face strict local privacy laws, meaning they must undergo a long process of verification with all users positively opting-in before they can be signed up. The sites are also prohibited from sharing certain user data with advertisers. But US companies are exempt from these rules under "safe harbour agreements" between the US and the European Union. Thus the company is not able to compete with Facebook on a level playing field. However whether this is a disadvantage in the long run is unclear as prosecutions of Facebook, Google (especially YouTube) and other US web service providers may force them to align with EU standards of privacy in the future as legal processes develop.

XING has been intent on monetizing its user base - without alienating them:

- Cleverly, XING has carefully expanded its range of offerings into adjacent key areas that have high growth potential. This is illustrated for instance by its jobs portal, with more than 24,000 expert groups and networking events from London to Beijing to New York. Another much used feature of XING is that it allows users to see how people are connected, making it into a more valuable tool for generating new contacts.
- With a quality offer like XING, use of viral marketing is most important factor and in some ways stems from that attention to high quality of service as perceived by its users. Members recruit the new members. Thus any other advertising must be low-level but efficient, to mark presence but not insist.
- The high quality of service also has led to low churn rates - with its customer services department employing around two thirds of all employees. Compared say to other websites,

or to other services industries (utilities, mobile operators, this appears to be comparatively high).

Against the rivals from the USA, such as LinkedIn, XING has a far better position, compared to those European national pure social networking sites in competition with Facebook. For example, the StudiVZ group of three websites were collectively the German market leader with 13.8m users, with Facebook growing rapidly (over 11.5m in the first half of 2010) to overtake while growth of StudiVZ was flat. In Spain, Facebook overtook social networking national leader, Tuenti, in 2010, gaining 10.5m users compared with the Spanish site's 6.8m - Facebook's users tripled in a year.

Since start-up, XING has used all forms of VC funding, from a business angel in May 2004, to a leading European Venture Capitalist with offices in Switzerland, Germany and the UK, for a net total investment of €11.4M. The first investment was from BrainsToVentures, an Angel investor, in May 2004, of €5.7M and in November 2005, a further €5.7M investment for Series A shares came from the VC Wellington Partners. The company listed on the Frankfurt Stock Exchange in 2006. With an IPO in 2007, growth has been organically funded, with the shares offered being taken by various large investors. Since that time, XING has been cashflow positive. The founders are keen to keep XING independent and not sell out to a large corporation. "*We decided to go public in 2006 in order to stay independent*", said the XING co-founder, Lars Hinrichs in 2008. The company has also spent a total of at least €13.5 M on acquisitions, of amiando, in Dec 2010 for €10.2M, Social Median, Dec 2008, and cember.net, Jan 2008 for €3.25M and Neurona Networking, June 2007 (undisclosed).

German media giant Burda Digital purchased a 25.1% share in XING In November 2009. This made Burda the largest shareholder in XING. The 1.3 million shares were sold to Burda by Cinco Capital, the investment vehicle owned by Lars Hinrichs, at €36.50 per share, in a €48.3M deal.

Overall, the company may be considered a reasonable success, for two reasons – firstly its business model which has ensured survival in a highly competitive market - and thus its growth in members, revenues and profitability, with a sustaining move into adjacent sectors through acquisitions. Secondly, despite some acquisition write downs for its foreign operations, XING has continued to grow in revenues during 2011 with rising profits, and a first-time dividend.

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A1.2 Display technologies

Cambridge Display Technology (CDT)

Cambridge Display Technology (CDT) is a subsidiary of Sumitomo Chemical of Japan. CDT is headquartered at Cambourne near Cambridge, UK, and was originally spun out of Cambridge University in 1992. Today it leads the research and development of organic light emitting polymer technology used in displays, and with potential application in lighting and other organic semiconductor applications. This technology is often referred to as OLED (or P-OLED), standing for 'polymer organic light emitting diode'. CDT holds an extensive patent and know-how portfolio relating to the use of conjugated polymers and the manufacture of devices based on them.

CDT was founded after initial work at the Cavendish Laboratory. While working in the research group of Professor Richard Friend, Jeremy Burroughes (now CTO of CDT) discovered that Light Emitting Diodes (LEDs) could be made from polymers as opposed to traditional semiconductors. Professor Friend, Dr Burroughes and Dr Donald Bradley filed the original patent. Interestingly, the researchers found that that there were no funds available within the university to cover the costs of patenting their discovery; Burroughes used his student loan to cover the costs.

The team found that the polymer, poly p-phenylenevinylene (PPV), emitted yellow-green light when sandwiched between a pair of electrodes. Initially this proved to be of little practical value as its efficiency was very low. Changing the chemical composition of the polymer and the structure of the device, however, brought efficiency of 5%, bringing it into the range of conventional LEDs. The research team realized the huge potential of the discovery and, after taking out key patents on the polymer technology, they went on to establish CDT to commercially exploit their findings.

Formation and investment

Despite the interest in P-OLEDs, Friend was unable to reach agreement with a British electronics company to license and develop the invention. 'It wasn't that the companies weren't willing to license the patent,' stresses Friend. 'It was more that they did not see organic light-emitting diodes as a core business and I was concerned that they would simply sit on our idea and not do the work needed to develop it,' comments Friend.

The university lacked the resources and skills to licence what was a potentially disruptive technology and so a new company was spun out. Nevertheless, it was difficult to attract the necessary initial investment, largely because the business model at that time was far from clear. In 1992, Friend founded CDT Ltd, with support from the university and funding from local seed venture capital fund, Cambridge Research and Innovation Ltd. The ownership of the OLED IPR was transferred from the university to the new company, while the university remained as one of the company's largest shareholders. Other early investors included the rock group, Genesis; the Sculley Brothers; the Generics Group; Hermann Hauser, a founding director of Acorn Computer; Steve Kahng, president of Power Computing Corporation; and Esther Dyson, president of Edventure Holdings, of New York.

In September 1997, further investment of about $10 million came from a financial group headed by Lord Young of Graffham, former Secretary of State for Trade and Industry in the UK government, who also became Chairman. Later in the year, Intel also invested in CDT. Even so these developments were not sufficient to keep CDT independent.

In July 1999, the company secured new equity funding of $16 million from Kelso Investment Associates and Hillman Capital, both based in New York. This transaction transferred the ultimate parent company of CDT to the USA and the majority ownership to the new US investors.

As part of their acquisition, Kelso and Hillman provided additional funding of $16m directly to the company to finance ongoing research and development activities. Relations with the new parent company were turbulent, however, and the CEO at the time (Danny Chapchal) left the company and the founder, Richard Friend, formed a new company, Plastic Logic to which he switched his allegiance.

In March 2001, a further $28m was raised from shareholders. These funds were raised partly to finance construction of a new $25m facility dedicated to developing commercial scale production techniques and know-how for LEP technology, in order to assist licensees in developing their own manufacturing operations.

In 2004, CDT was floated on the NASDAQ National Market and, in 2007, it was acquired by the Sumitomo Chemical Company, for about $285 m. Why did CDT's investors sell? In short, P-OLEDs had taken too long to get into the market, and Sumitomo offered double the share price at the time. “The share price in the market has been hovering between $6 and $7. The last time it was anywhere near $12 was the end of 2005," Fyfe told Electronics Weekly. "The board had to take into account how many more times the company has to go to the market. It was a risk-assessment exercise."

In all CDT raised over $250 m from various sources but it was still not enough for it to fully develop and commercialize its technology. This is not to say that CDT is a failure but rather to recognize that the commercial exploitation of advanced materials is typically a very lengthy process and sustained investment is required over a considerable time period. (Note that Polypropylene, Teflon, and carbon fibre all took decades to fully realize their commercial potential.

Exploitation strategy and technological difficulties

On its formation, CDT's plan was to become a materials manufacturing company, but in practice it concentrated on developing new technologies and licensing them to other companies. By 2000 CDT had made commercial agreements with Philips, Uniax, Hoechst, DuPont, Seiko Epson, Delta Electronics and Agilent Laboratories.

With the 2000 takeover, a new business strategy was developed, the aim being to provide a 'one stop solution' for licensees. By forming partnerships with companies throughout the displays value chain, potential licensee could approach CDT and be able to immediately acquire all the knowledge required for display production, avoiding the need for them to do independent development work. It would also give licensees immediate access to all materials required for display manufacture

The growth in CDT's patent portfolio is a measure of the company's R&D achievements, and the need to build a family of patents around the core IP. By 2002 the number of patents held had risen to 140, the product of the company's steadily growing workforce, which had reached 150 by 2002. Revenue growth, however, was volatile - $27.5 m in 2001, $7 m in 2001 and $13.5 m in 2003. By 2010 CDT had over 560 patents granted worldwide in 280 families.

Meanwhile, there were technological barriers to development. One of the challenges was how to increase the lifetime of its blue polymer, which initially only lasted for 1000 hours versus over 40,000 hours for red and 20,000-30,000 hours for green. This would have serious implications for the life of, sat, a TV screen. Halving the brightness of the blue polymer doubled its lifetime, but this characteristic has proven a barrier both technologically and commercially for the company. New materials continue to be developed with strong improvement in performance: by 2010 blue lifetimes were up to 26,000 hours while green was up to 200,000 hours and red up to 350,000 hours.

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Plastic Logic

Plastic Logic is a supplier of innovative organic flexible displays, based on its proprietary technology for plastic electronics, PlasticPaper™. Over the last twelve years, the company has developed a technology that enables silicon to be replaced by plastic in integrated circuits and so created a flexible electronic display with a continuous substrate. Commercial application of the technology yields display modules that are claimed to be more robust, flexible, lighter and cleaner to manufacture than traditional glass and silicon displays. They can be far larger and lower cost than conventional displays, potentially with higher process yields in manufacture. Using this display technology, the company is developing a second-generation e-reader product. Plastic Logic sees itself as leading a revolution in visual information technology.

Founded in 2000 by researchers at the Cavendish Laboratory of Cambridge University in the UK, Plastic Logic now has its R&D centre in Cambridge, with a high-volume, state-of-the-art manufacturing facility in Dresden, Germany and product engineering, sales and marketing and executive management being headquartered in Mountain View, California, USA. The manufacturing plant in Europe, in the capital of the federal state of Saxony, Dresden, is at the heart of the German electronics industry - sometimes called "Silicon Saxony". Germany and the Saxony region offer significant financial support grants for starting up new high technology research on manufacturing processes and production facilities.

International investors, principally RUSNANO, a Russian high tech fund, are now supporting the build of a second production line in Russia, at Zelenograd. This plant will be aimed at a future e-reader for Russian schools, the Plastic Logic 100, featuring a large, thin, lightweight screen based on the PlasticPaper™ technology with rugged construction.

Plastic Logic's history

The origins of Plastic Logic lie in the mid-1980s, when Professor Sir Richard Friend (now Cavendish Professor of Physics at the University of Cambridge) started research into organic semiconductors. By 1988, the Cavendish Laboratory research group had managed to make an organic transistor from the conjugated polymer polyacetylene. It took almost a further decade of research efforts before mobility of polymer semiconductors approached silicon device levels in the laboratory, in 1997.

However, before large companies or venture capitalists could be persuaded to invest in the discovery, a practical manufacturing process had to be demonstrated for the new transistor technology. At the time, the Cavendish Laboratory was developing inkjet printing to deposit polymer light emitting diodes (P-LEDs) on substrates for displays, later to be exploited by a sister spin-off company, CDT. Within a few months this process had been adapted to print transistors. The first simple circuits performed reasonably well. But the next step in development of organic transistors required engineering a practical product, with a well-focused industrial environment, and not pure research science any more.

Plastic Logic was then founded in January 2000 after key team members had approached business angel and venture capitalist Hermann Hauser and received seed funding. He had been an early investor in CDT and was a co-founder of the VC company Amadeus Capital Partners in Cambridge. Even without a clear business plan, he and Amadeus agreed to invest in the commercial development of organic polymer transistors. Over the next few years, Plastic Logic went through several funding rounds so that by 2006 it had developed its plastic transistor technology sufficiently to produce a display with a million transistors. The company then produced a key application for its display – an e-reader product for business, the Pro-Reader.

Overall, Plastic Logic had raised more than US$200 million over its first decade to 2010. Of this, some US$100 million was raised in late 2006 to build an advanced manufacturing plant in Dresden for display modules for electronic readers, to start production in 2008. This was one of the biggest venture capital rounds ever in Europe. Led by Oak Investment Partners and Tudor Investment, the existing investors Amadeus (seed funding) Intel Capital, Bank of America, BASF Venture Capital, Quest for Growth and Merifin Capital also participated. While R&D remained in Cambridge, product development moved to Mountain View, CA, with the corporate headquarters.

Exploiting its Dresden production line, Plastic Logic launched a prototype monochrome e-reader, the Que Pro-Reader in mid-2009 in the USA. It delivered perfectly rendered PDFs - unlike Amazon's devices of the time - with a strong potential appeal for business users as a featherlite document reader, being ultra-thin and more attractive than Amazon's Kindle. Plastic Logic then signed deals with AT&T to sell its 3G model and with Barnes & Noble as retailer for the USA. Moreover, the news media signed on as partners—the Wall Street Journal, USA Today, the Financial Times, Forbes etc. However, customer delivery was long-delayed and finally abandoned in August 2010 amidst rising competition for portable electronic displays and e-readers. Especially significant was the iPad launch in early 2010, which transformed market expectations. Moreover over 2009-2010, Apple advanced, launching the slender, larger screen colour iPad, cutting retail prices and attracting business users, while Amazon revamped the Kindle DX, adding full PDF functionality, slimmer size and price, yet upping readability. The Que's pricing was just too high – at $649 for WiFi-only - against the iPad at $499 for WiFi only, while the Kindle DX with 3G dropped 20% to $379.

However, the company was driven to continue by the core concept - that plastics can replace silicon in transistors - so the basic technology was still valuable enough to merit persisting with the venture. Plastic electronics promise economic, manufacturing, energy efficiency, form factor and environmental benefits over silicon semiconductor and glass-based displays. So simultaneously, the company then entered negotiations with a Russian state controlled investment company, RUSNANO, for a capital infusion that would eventually see control pass to the new investor. In November 2010, Plastic Logic announced new funding which would give the state–owned Russian Corporation of Nanotechnologies a 25% stake in the company for USD 150 million. Furthermore, RUSNANO would help Plastic Logic secure $100 million in debt financing. Interestingly Plastic logic was billed as a "U.S.-based electronics technology company", in its press coverage[54] for this, putting forward its Silicon Valley/USA credentials. This round of financing also gathered an additional US$50 million from Oak Investment Partners which remained the largest shareholder, with 52% and a handful of others. The financing from both was to be dedicated to building a new production facility, in Russia.[55] Plastic Logic noted at that time that a further $400 million of additional debt and equity would be raised over the next few years. CEO Richard Archuleta noted at the time *"...we found investors with a long-term view that share our vision for the next five to 20 years and have the resources to support us. These were sovereign or state-backed funds in the Middle East, China, Singapore and Russia and every group has their view but we think we found the best partner in RUSNANO"*.[56]

In late 2011, Plastic Logic took an injection of a further £440 million (US$700 million) from RUSNANO to keep afloat, and started construction of the second production plant in Russia. The market for its first mass produced e-reader, the Plastic Logic 100, features a capacitive touch screen. Its first market will be in the public sector, for Russian schools at US$400 per unit, and ultimately retailed at a fairly high price of US$800. It was rumoured that RUSNANO fought off Chinese interest for a second factory to be built in the Beijing region. It was also noted that

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54 Invest-IQ, 25 January 2011, http://invest-iq.net/2011/01/rusnao-acquires-25-of-plastic-logic-for-usd-150m/

55 RUSNANO noted at the time: "We are making an unprecedented investment of close to a billion dollars in the future of plastic electronics to help create one of the largest commercial centres for it in Russia. This investment signifies the potential that we see in the future of plastic electronics across a variety of commercial and consumer products. Flexible plastic electronic displays will provide another major milestone in how people process information. Entering this new disruptive segment at the stage of its inception gives Russia a chance to win a leading position in global market of future electronics."

56 James Mawson, 2011, *Russia Leads $700m Investment In Plastic Logic,* Wall St Journal, 18 Jan 2011.

RUSNANO is a long-term investor and so may not have squeezed Plastic Logic for a typical private equity-style rate of return, or annual performance measure over three years.[57]

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Novaled AG

Novaled AG is a leading supplier of specialist materials in the OLED (Organic Light Emitting Diode) field. It specializes in high efficiency long lifetime OLED structures and organic electronics. The company is known for its own OLED technology, but particularly for its proprietary OLED materials and its customized OLED products and services. Novaled also specializes in OLEDs on metal. It sees four markets for its technology: flat panel displays; lighting; solar power with organic photovoltaics; and printed organic electronics for all functions. Its OLED materials and technologies are supplied to the leading display manufacturers, e.g. Samsung. In May 2011, Novaled claimed to have developed the world's most power-efficient fluorescent white OLED structure, using its proprietary organic materials, increasing light emission by more than 80%, yet with lower manufacturing costs.

The company was spun off in 2001 from the Technical University of Dresden's Institute for Applied Photophysics (IAPP) and the Fraunhofer Institute (FhG) for Photonic Microsystems (IPMS), both of Dresden, Germany, by four key people. These were Prof. Karl Leo, Dr. Martin Pfeiffer, Dr. Jan Blochwitz-Nimoth and Jörg Amelung, aiming to specialize in OLED displays. Commercial operation began in March 2003. Originally, the aim was contract research in OLEDS, using Novaled's expertise in the production (materials, mixing systems, layer order, material handling) and in suitable thin-

[57] James Mawson, 2011, *ibid.*

film systems of organic materials suitable for production on large-area substrates by vacuum evaporation.

Currently Novaled employs some 120 people, worldwide. Novaled's headquarters are in Dresden, with branches in Korea and Japan. In 2010 it had €11mn revenues and also became profitable. It claims 450 patents in organic dopants with a further 50 submitted. Novaled has developed long-term partnerships with major OLED producers throughout the world and licences its technology to larger players in OLED display screen and lighting manufacture. For example, Novaled supplies materials and process technology to Samsung for their OLED displays. Also Novaled may launch their own consumer brand for new lighting systems with OLED sources.

Its key proposition is OLEDs working at very low voltage, up to three times lower than conventional OLED technology, giving longer long battery lifetimes for portable devices and high efficiency for displays. Further expertise has been developed in OLED films on steel and aluminium substrates. This has led to a series of co-developments with commercial companies and publicly funded institutes:

- Collaboration with Philips of the Netherlands led to a May 2005 announcement of a new efficiency record of high-brightness white OLEDs by combining Philips' technology for an OLED device with materials from Novaled's proprietary doping technology for high efficiency.
- Together with steel producer Arcelor Mittal, Novaled has been developing OLED structures for steel substrates since 2006.
- In 2006, Universal Display Corporation, of the USA and Novaled teamed up to produce red phosphorescent OLED Devices. These employed Novaled's proprietary doping technology and materials for very low voltage OLEDs.
- Novaled has also been researching OLEDs on flexible aluminium substrates since 2007, principally in Rollex, the German project on roll-to-roll process development.
- In 2009 Novaled and the US company Plextronics[58] started a joint development on more advanced kinds of OLEDs.
- Collaboration started with the Holst Centre,[59] Eindhoven, Netherlands, on organic electronics, specifically organic thin film transistors (OTFT) using the Novaled technology and materials, under a joint development agreement, announced March 2009. The objective is to investigate

[58] Plextronics Inc, of Pittsburgh, PA, USA produces printed solar, lighting and other electronics, particularly organic solar cell and OLED lighting. It specializes in the conductive inks and process technologies that enable those and other similar applications.

[59] An independent open-innovation R&D centre developing generic technologies for Wireless Autonomous Transducer Solutions and for Systems-in-Foil.

Novaled's dopants in Holst Centre's organic thin film transistor technologies for displays and circuits.

Note that a key feature of the Holst Centre (named after the first director of Philips Research) is its partnership model with industry and academia around shared roadmaps and programs. Holst Centre was set up in 2005 with support from the Dutch Ministry of Economic Affairs and the Government of Flanders, by IMEC (a Flanders, Belgium public sponsored contract research institute) and TNO (of the Netherlands, with a similar status). Located at High Tech Campus in Eindhoven, Holst Centre has over 145 employees from around 25 nationalities and a commitment from close to 20 industrial partners.

The location of Novaled, and IPMS, in Dresden is strategic, because the city has a long tradition of excellence in microelectronics dating to before reunification in the early 1990s. There is also a growing industrial presence in organic optoelectronics in Dresden—the Dresden area is viewed as an emerging "organic electronics valley" in the middle of Europe. Note that Fraunhofer IPMS is one of 11 non-profit Fraunhofer institutes that address the area of microelectronics. The overall mission of these Fraunhofer institutes is to help drive technological innovation by performing contract research and development work in support of industry and government agencies. The annual budget for the IPMS is EUR 24 million, with 40% generated from industrial contract research. Within IPMS, the Centre for Organic Materials and Electronic Devices (COMED) carries out development research in OLEDs for lighting, signage, and displays (NSF WTEC 2010). COMED is increasingly focused on organic photovoltaics (OPV). This centre employs approximately 60 personnel, with an annual budget of €6 million/year, and world-class facilities for processing OLED displays and OPV cells on glass and stainless steel. The focus is primarily on vapour-deposited small-molecule organic semiconductors. Much of the work at COMED is motivated by the commercial interests of nearby companies, as is characteristic of Fraunhofer institutes, in this case in the OLED and OPV industry, such as Novaled and Heliatek, (NSF WTEC 2010).

Novaled's direct capital funding (as opposed to technology injections) throughout its growth has been VC sourced, with its third round finance being in 2009. Its main investors include the German VC, eCAPITAL, also Crédit Agricole Private Equity, TechnoStart, TechFund and CDC Innovation. On 30 September 2011, Samsung of Korea invested an undisclosed sum in Novaled in order to increase its presence in the OLED space, through the venture capital arm of the Samsung Group, Samsung Venture Investment Corporation (SVIC). Previously, in a second round of funding, Novaled GmbH had secured €15 Million, on 01 December 2005, and its conversion to a stock company status (of AG) was prepared. On 14 May 2003, Novaled GmbH secured €5.75 million in first round financing from a consortium of international investors led by venture capital firms TechnoStart and TechFund

Capital Europe. Additional investors included Dresden Fonds, tbg, and Thomson, the media services and equipment group.

For its supply side, there are long-term contractual agreements in Germany with Ciba Specialty Chemicals and BASF, who produce the organic dopant and transport materials, which are checked by Novaled. Consequently, Novaled is not capital intensive as it harnesses outside materials production. Novaled specializes in materials sciences, optics, biochemistry, prototyping and production engineering, offering IPR on OLED structures and materials to support its OLED technology, but does not produce whole display screens or manufacture the OLED plastic film needed to make them. Its business model is thus to sell proprietary materials, dopants and transport materials (produced by it supply chain of CIBA and BASF) with its IP licences, so it acts as a technology provider, not a manufacturer. For those who would produce displays or lighting from its technology, it is possible to use existing plants and half of the equipment in them.

The company has strongly benefited from German government support, as well as being spun off from a technical university and a state-aided research institute. The key project has been the Rollex project: a programme established to further expertise in roll to roll production (R2R) for processing and manufacturing of organic electronic substrate films. The Fraunhofer IPMS, Dresden IAPP, Novaled, and others are members of this project, which was funded starting in 2007 by Germany's Federal Ministry of Education and Research for the development of the R2R production processes for highly efficient OLEDs on flexible substrates. The objective of the programme is to establish a stronger fundamental knowledge for processing and manufacturing using R2R equipment. The Rollex project follows the industrial strategy in Germany and particularly of the Saxon region and Dresden's institutes, that a "bridge" between university and industry is critical for successful product commercialization. One example of such a "bridge" is the Fraunhofer IPMS. The IPMS in Dresden enables the IAPP of the Technical University of Dresden to scale-up its technology in a well-controlled environment (NSF WTEC 2010).

Novaled's business model has evolved since 2001 towards materials and process technology IP for lighting, organic thin film transistors and solar cells, as well as displays. When Novaled started as a spin-off from Fraunhofer and Technical University of Dresden in 2001 with just 4 people, the idea was to market its doping technology for OLEDs along with its proprietary materials. Today, Novaled offers technology transfer packages (licensing and IP) in manufacturing and engineering, as well as R&D contracting for dedicated development programmes to enhance the performance of a client's products and also training courses. For the lighting market, Novaled produces it own tailor-made OLED sources on glass or metal substrates for the lamp and luminaire suppliers.

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E Ink Corporation

The pioneering research into electrophoretic 'electronic ink' was first conducted at the MIT Media Lab. E Ink was a spin-off from MIT, founded by Joseph Jacobson of the MIT Media Lab in 1997, to advance electronic ink further with display developments based on this technology. Since incorporation, E Ink has gradually advanced both the core technology of the electrophoretic materials and the applications for electronic ink displays selling micro-encapsulated ink imaging films and prototyping kits. Originally, E Ink Corporation was headquartered in Cambridge, Massachusetts and was a privately held company. It was bought by a strategic partner, PVI (Prime View International) of Taiwan in 2009 for $215 million. At buy-out E Ink had around 127 employees, with its VP for R&D coming from Kodak. In its last independent quarter, E Ink sales were $18M in Q1 2009, an increase of 157% over Q1 2008.

In 2009, the ePaper display module market was expected to grow to over $3 billion by 2013, with the emergence of colour displays and flexible displays, for the eBook and eTextbook, eNewspaper/eMagazine and eDocument markets. At that time, electrophoretic display technology had more than 90% market share in the overall ePaper displays, and E Ink was the leading supplier of electrophoretic materials.

The E Ink team made its breakthrough over 1997-1998 when it successfully microencapsulated a micromechanical display system, creating a flexible display material with excellent reflectivity, viewing angle and contrast ratio. The patented microencapsulation process enables suspension of display material in an ink form with design and manufacturing advantages. In addition to paper-like readability, E Ink's technology offers low power consumption and a thin, lightweight form factor. The resulting 'electronic ink' has many applications, from point-of-sale signs in retail stores, to next generation displays in mobile phones, tablets and electronic books. E Ink envisioned a new RadioPaper™ to be coupled with broadband communications for anytime, anywhere information. E

Ink and PVI support nearly 20 eBook manufacturers worldwide. In addition to electronic books, E Ink's Vizplex™ imaging film is used in mobile phones, signage, smartcards, memory devices, and battery indicators.

However E Ink did not go into volume production of its electronic ink films as part of an electronic display. Instead, PVI in Taiwan with its capital intensive manufacturing facilities acted as the production centre for E Ink's technology, embodied in the electronic ink materials, to make the rest of the electronics and assemble all into a electronic paper display product. Thus E Ink, through PVI, seeded the e-reader market from 2005 on and they have remained as the e-reader display market technology leaders ever since. With this approach, E Ink avoided the need for far larger capital injections, for production facilities and staff, of the order of billions of dollars.

As a key input to its e-reader initiative, in 2005, PVI acquired the ePaper business of Philips Electronics. It then partnered with E Ink on production of displays for electronic books, such as Sony's e-reader and the Amazon Kindles. In 2008, PVI bought a 74% stake of Hydis Technologies of Korea, to quadruple capacity for the transistor backplanes used in ePaper. Also PVI invested heavily in dedicated driver chips and most importantly, the touch screens for ePaper, as well as flexible displays for future products. The E Ink deal was the final step in the transformation at PVI over the period 2005 - 2009 into a specialist in electronic paper displays. It secured its supply of a critical component during the rapid growth phase of the e-reader market.

E Ink's customers are those making display devices of any kind and include Amazon (the Kindle series), Samsung, Sony, Casio, Citizen, Hanwan, Hitachi, iRex, Lexar, and Plastic Logic. Sony launched its PRS-700 Reader with an integrated touch screen using E-Ink display film. Chinese astronauts took a Hanwan N510 eBook into outer space on a Shenzhou 7 mission. PVI, Epson, LG Display, PolymerVision, Hewlett-Packard and Plastic Logic have all demonstrated flexible active matrix displays using E Ink Vizplex imaging film. The first ePaper animated magazine cover, *Esquire*, in May 2009, used E Ink Vizplex. In the USA, Verizon debuted the Samsung Alias 2 cellphone, with a changeable keypad made with E Ink Vizplex.

In its first equity round in 1998, E Ink raised $15.8 million. By 2002, E Ink had raised over $100 million, largely though strategic investors In January 2000, the company completed a second round of equity financing, raising $37.1 million. E Ink then pursued a third round of financing in February 2001, with a $7.5 million investment from Philips Components, as part of a joint development for the use of electronic ink in handheld device displays. In February 2002, TOPPAN, a Japanese printing technology company, added to its initial $5 million investment in 2001, with a further $25 million, for a strategic partnership to commercialize electronic paper. Early investors in E Ink included a wide range of leading technology companies, publishers and venture capitalists.

E Ink has 150 patents in the USA, plus some in other countries. This portfolio provides wide coverage as E-ink holds patents not only for displays, but also for methods of manufacturing the required materials, processes for assembling finished displays, and techniques for integrating the displays into finished products. While many of E Ink's patents are focused on electronic paper, some have broader applicability in fields like organic electronics and flexible semiconductor manufacturing. It has over 100 additional patent applications pending. E Ink's achievements were recognized with business and industry awards in 2008, including The Smaller Business Association of New England (SBANE) Top Innovator Award; the Boston Business Journal's List of Boston's Fastest Growing Companies; The FineTech Japan Display Components & Materials Category Grand Award.

Note that many such technologies were coming to market over the period 1998 - 2010, though whether the first would be the monochrome frontrunner, E Ink, or one of its competitors, was always unclear. Other colour e-paper technologies were also being pursued, for instance, Fujitsu's FLEPia was a colour e-reader shown in 2008, and technologies from Ricoh, Pixel Qi and Qualcomm might easily have taken the lead. E-Ink leads with its improved Pearl greyscale technology and then with its Triton full colour form launched in 2010 to maintain its grip on the e-reader market. Its lead was built up using its Pearl greyscale technology for Amazon's Kindle, Barnes & Noble's Nook e-reader, Sony's e-readers and Plastic Logic's Que.

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Eastman Kodak

Eastman Kodak Company, commonly known as Kodak, is an American multinational imaging and photographic equipment, materials and services company. Founded in 1880 by George Eastman, Best known for its photographic film products – a market it practically created on its own and which it dominated throughout the twentieth century – Kodak also was first to discover Organic Light Emitting Diodes (OLEDs) in 1979.

Kodak was an analogue giant that failed to make the transition to the digital age. It once had a market value of over $30 billion; in January 2012 it filed for bankruptcy. It has been unprofitable since 2007 and, on filing for Chapter 11 protection, employed about 18,000 people, down from 145,000 at its height. Kodak has announced that it will stop making digital cameras, pocket video cameras and digital picture frames in 2012, focusing on photo printing, through retail and online services as well as desktop inkjet devices and licensing its brand name to other manufacturers.

The story of Kodak and its attempt to commercialize OLEDs perhaps mirrors the overall story of its demise. Kodak researcher, Dr. Ching W. Tang, created the first efficient OLEDs in 1979 while experimenting with solar cells. With his colleague, Steven Van Slyke, he developed the first multi-layer OLEDs in 1987. In 1999, after 20 years of continued research, Kodak in partnership with Sanyo (SK Display Corporation) produced the first OLED display.

Kodak was one of the first companies to start its own industrial lab in 1912. Kodak conducted world-leading research in areas related to its business products (akin to Bell Labs or Xerox) and made numerous breakthrough discoveries and inventions throughout the twentieth century. Kodak inventors were issued with 19,576 US patents between 1900 and 1999. For instance, Kodak scientists invented the photoresist in 1937 (a type of photosensitive resin later used to manufacture integrated circuits), the digital camera in 1975, and as mentioned, OLEDs in 1979.

OLED pioneer

Kodak believed that its OLED display screens would displace liquid crystal displays (LCDs) in digital cameras and a range of other electronic products. Kodak's technical successes initially looked as if they would bring commercial success as resulted in licensing revenues started to grow. A joint venture with Sanyo was started in 2003 called SK to mass-produce OLED screens for Kodak and other manufacturers. The Kodak EasyShare LS633 Digital Camera in 2003, the first camera to feature an AMOLED display, proved to be the high point though, as its efforts to capture a slice of the slowly growing OLED market stuttered and eventually failed. The company also developed manufacturing equipment and technologies around its chosen approach to producing full-colour displays: white OLED with colour filters. Most recently, Kodak has been pursuing OLED lighting.

With its digital strategy faltering and problems accumulating across the company, in 2007 Kodak announced a cross-licensing agreement with Chi Mei Optoelectronics and its affiliate Chi Mei EL (CMEL), enabling CMEL to use Kodak technology for active matrix OLED modules in a variety of small to medium size display applications.

Kodak also explored the use of OLEDs as a lighting solution, receiving a $1.7 m Department of Energy grant in 2009 to research and develop processes for lighting.

Sale of OLED assets to LG

By the end of 2009, with things turning from bad to worse, Kodak sold its OLED-related assets to LG for a reported $100 m. Thus, after 40 years of fundamental research, materials and device development, display manufacturing, materials sales and licensing activities, the inventor and first developer of OLED displays exited the business. Kodak's "small molecule" technology, in the form of materials and intellectual property, enabled OLED to become a mass-production display technology, with numerous display developers licensing Kodak technology and manufacturing using vapour deposition through fine metal masks. The vast majority of OLED displays produced to date use Kodak's technology and/or materials in some form. This has enabled what is now a billion-dollar industry on the verge of even significant growth, according to analysts Display Search.

LG formed a new company, Global OLED Technology (GOT), to exploit Kodak's two thousand OLED related patents, and license them to other companies. In early 2012 LG showcased a 55" OLED screen TV to demonstrate its technical and manufacturing prowess, forecasting that it will sell 200,000 to 300,000 OLED TVs in 2012, and up to 2 million in 2013. Although industry analysts believe these targets are optimistic, it appears that we have reached the point at which LCD technology starts to give way to OLEDs. In response to LG's move, Samsung the dominant player in LCD technology, announced in February 2012 that it was spinning off its LCD business, Samsung Display, which reportedly made a loss of $650 m in 2011. In a parallel move, it was rumoured that Samsung Mobile Display (the OLED company formed in 2008) would be brought fully under the control of Samsung Electronics.

These moves strongly suggest that the long talked about commercial breakthrough of OLED technology has finally arrived – unfortunately too late for Kodak. Between them, Samsung and LG were expecting to invest $17 billion between 2011 and 2015 in OLED technology and manufacturing.

Reasons for failure

The failure of Kodak in OLEDS has to be seen within the context of Kodak's overall failure to make the transition from the analogue to the digital age. As late as 1976, Kodak accounted for 90% of US film and 85% of camera sales, according to a 2005. It is widely thought that this apparently unassailable competitive position resulted in an unimaginative and complacent corporate culture.

A string of CEOs over the past twenty years presented digital strategies and on the surface Kodak seemed to be making a strong showing in the digital arena, but ultimately Kodak was unable to move fast enough to stave off the Japanese competition. Throughout the last decades of the twentieth century, Kodak's focus was always on its massively profitable analogue film business. When it became clear that film was in terminal decline, Kodak tried to jump to digital, but Sony, Canon and others were years ahead. Moreover, a completely different business model was called for – in the analogue world, cheap hardware and expensive consumables laid the golden e.g. but in the digital era hardware margins were still slim and software was largely free.

Kodak's virtual monopoly in colour film was a cash cow. This good fortune led to a company heavy with staff, needless jobs, many layers of management and generous employee benefits. Plenty of cash allowed Kodak to invest in research of all kinds and branch out into other lines of business. With regard to OLEDs, it took 30 years for a market for the technology to develop, for the dominant LCD technology to wane. That timeframe could have been shortened if Kodak had instigated a better strategy, marketed the technology better and invested more. Nevertheless, there is no doubt that the development of advanced materials has a long gestation.

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A1.3 Robotics

iRobot Corporation

The iRobot Corporation designs and builds robots such as an autonomous home vacuum cleaner (Roomba), the Scooba that scrubs and cleans hard floors, and military and police robots, such as the PackBot. The company was formed in 1990 by Rod Brooks, Colin Angle and Helen Greiner, who previously had worked together at MIT's Artificial Intelligence Laboratory. It was incorporated in 2000, when it merged with Real World Interface and changed its name from IS Robot to iRobot.

Headquartered in Bedford, MA in January 2011 the company employed 657 full-time staff, of whom 304 were in research and development, 156 in operations, 78 in sales and marketing and 119 in general and administration. In 2010, its sales revenue was about $400 million, with gross profit of $145 million. It has a market cap of over $700 million.

The company's early robots, e.g. Genghis (1991) grew directly out MIT research. Its early business plan was built around space exploration by robots. iRobot worked with NASA and other organizations to develop a robot for lunar exploration, but commercial success was limited. Through the 1990s, the company grew slowly, on the back of government and industry contracts. Several products were developed with mixed success (e.g. MicroRig, the result of partnership with the oil industry to develop a fully autonomous robot to collect data from functioning land-based oil wells; and My Real Baby, in collaboration with the toy industry, a doll with sensors). In response to a 1997 US government grant, the company began work on a line of research robots that could be used in urban combat. At about the same time iRobot was asked by the British Ministry of Defence to work on robots for bomb detection and disposal. These two lines of research eventually merged into the PackBot program. By January 2011, over 3,500 PackBot Robots have been deployed worldwide, mostly in Iraq and Afghanistan.

At the same time the company was working on a large cleaning robot for SC Johnson Wax that would eventually be released as the AutoCleaner. As the AutoCleaner project wound down, a team was assembled to develop the world's first affordable home floor cleaning robot. It took five years from prototype to product for the Roomba, the world's first affordable home vacuum cleaning robot, launched in September 2002. Over six million home cleaning robots have now been sold.

Prior to iRobot, robots were typically large industrial robots, academic experiments or just gimmicks. The iRobot business plan was built on the premise that there could be practical applications that offered value beyond their cost. Funding for their vision didn't come from venture capital but rather from the SBIR Program, specifically through DARPA. "What we were trying to do was so risky that no rational investor would give us money," recalls Colin Angle, chairman and chief executive officer of iRobot. "The SBIR Program would listen because they were looking for innovative research." SBIR awards supported 33 iRobot research initiatives, contributing more than $30 million in funding for the development of new sensors and enhancements to the robots' capabilities. Angle said. "I can say with absolute certainty that without the help of the SBIR program, iRobot could not have become the industry leader we are."

If SBIR funding through DARPA was the mechanism to see iRobot through the funding "Valley of Death", it is public procurement that has enabled it to grow and develop into a substantial company and market leader. For instance, in April 2011 it signed a four-year, $230 million contract with the

U.S. Navy, and in September 20111, it was awarded a five-year, $60 million contract to supply the US Army with more of its PackBot combat robots.

In its early days (e.g. Roomba) projects were vision-oriented and led by a top executive. The project team was design led and market research was less important than the project leader's intuition (Turilin, 2010). Later, the company adopted "Google- like practices with employees encouraged to use "free time" to work on their own ideas to develop prototypes. After Roomba's success, iRobot was gradually transforming into a consumer device company and later project decisions became very market oriented – projects that did not meet required market size, margin, and sales estimates got cancelled.

But this new project management approach was detrimental to the company's innovation capability: market and profitability standards discouraged risk-taking and data driven research replaced intuitive visions as the main decision making tool. As a result, later projects introduced either incremental improvement, were cancelled, or failed in the market (Turilin, 2010).

It is interesting to note that two of the three founders of iRobot have recently left to start new ventures, currently in 'stealth' mode – Heartland Robotics, and The Droid Works. The latter has also received SBIR support, while Jeff Bezos' investment company (Bezos Expeditions) has invested $7 million in the former.

Looking to the future, iRobot is developing new and innovative platforms, for instance aiming to make existing and future robots easier to use and more adaptable with its Aware©2 cross-platform software. AWARE©2 is a framework for creating complex robot software systems, making its robots easier to use, integrate, troubleshoot and support. The same software works on many different robots, so a single software engineer can quickly and easily program many robots without having to learn specialized languages for each one. AWARE©2 is open source software, i.e. iRobot supports third-party technical development and the commercialization of the resulting work. iRobot views collaboration with external developers as an essential way to provide a broad range of new capabilities to its products. iRobot is happy, for instance, that there is a Roomba hacking community. As Colin Angle has said:

"We're a company that … really loves the fact that [a Roomba hacking] community exists. Why do you think we made it so you can take the top off and find a beautiful serial port? Why do you think we published the API for the serial port? It's an expense but it was the right thing to do. People should hack robots. There is a cottage industry of people making money from Roomba accessories out there today. I hope that it will grow over time. People are getting excited and learning about robotics. Roomba is a durable, dependable and affordable platform for doing robotic research."

As well as continuing its home products and military robots, the company is pursuing new robotic forms (e.g. Jambots). For example, it has developed a jamming gripper (developed in collaboration with Cornell and the University of Chicago) which allows a robot to gently pick up an irregularly shaped object that traditional grippers might not be able to grasp, or might damage.

Another promising direction is in healthcare. In 2011, iRobot announced a $6 million investment and expanded partnership with InTouch Health, a leading remote presence telemedicine solution provider. The aim is to explore opportunities for healthcare applications on iRobot platforms. InTouch Health will provide access to FDA regulated healthcare facilities, providing iRobot with a route into hospitals, emergency care facilities, patient wards and operating and procedure rooms.

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Shadow Robot Company

Shadow Robot is a small, London-based robotics company incorporated in 1997 but with roots going back to 1987. It currently employs 12 people, and has annual sales revenue of about £350,000.

Shadow Robot is the brainchild of hobbyist, Richard Greenhill, an archetypal eccentric British amateur. In 1982, photographer Richard Greenhill realized that programmable personal computers would make robots possible and perhaps enable his vision of a general-purpose robot that could bring him a nice cup of tea. With no university degree, no university backing and very little funding, over a period of 25 years Greenhill and a small team developed the world's most advanced robotic hand.

The original aim of the Shadow Project was "to build a genuinely useful general-purpose robot, at a price which people, rather than just institutions, can afford". The strategy was to imitate the human body as far as possible, in terms of overall shape, size, freedom of movement, power and precision. Thus, Greenhill's earliest work was on building a biped, since the best-adapted body shape for human spaces is something like a human one. To that end, he designed the air muscle, which stretches and compressed like a human one.

Limited funding and management

Between 1987 and 1997, Shadow received a number of small awards and grants: e.g. from 1988 to 1991 it was part of the Department of Trade & Industry's (DTI) Advanced Robotics Initiative; in 1994 the Technology Enhancement Programme commissioned Shadow to create educational material introducing the Shadow Air Muscle to schools; and in 1997, Shadow shared a £22,000 grant towards the development of an aid for the disabled - the Shadow Ranger, a device to maintain range of motion in the knee joint of MS sufferers.

A significant breakthrough came in 1997 when a quantity of Shadow Air Muscles were supplied to NASA, and it was shortly after this that the company was incorporated. Greenhill is not a businessman and in 1997 Rich Walker joined, first as CTO and then Managing Director. Interestingly, Walker was a teenager when he first met Greenhill in 1987. As a Cambridge student he worked as a summer intern for Shadow; after graduation he worked as a volunteer.

Rather than pursue the biped, humanoid robot, Walker believed that it was the arm and particularly the hand that had commercial potential rather than the leg. Walker negotiated a SMART award of £45,000 from the DTI in 1998 for Shadow to start building its first real product: the hand. A further grant of £50,000 came from the National Endowment for Science Technology and the Arts (NESTA).

The company built on its air muscle technology to develop the most complex and anatomically accurate mechanical hand in the form of the Shadow C6M Smart Motor Hand. The latest model, C6M, uses 40 "air muscles" to manipulate 24 joints to replicate the movements of the human hand. It is equipped with sensors to provide tactile feedback to the processor. The hand has a list price of about $100,000, and is designed to be used for applications including telepresence, where an operator can control the hand remotely through the motion of their own hand; ergonomics research, and repetitive handling of fragile objects, such as fruits or eggs.

Shadow received its first order for the Dextrous Hand in 2004, curiously from the University of Bielefeld in Germany. Carnegie Mellon University also bought one in 2005 for their research work, but the main customer was again NASA who placed an order in 2005 in connection with their Robonaut project. NASA has not made public what it is doing with the hand, but it is believed that NASA took it apart immediately after purchase.

A company with potential

99% of the world's robotic arms are made by 12 multinational companies, such as Barrett Technologies and Germany's Schunk Group, but they are typically simpler or larger than Shadow's. Most are used in older industrial applications, e.g. car production, whereas Shadow Robot's hand is so dexterous that it is better suited to "emerging applications" that are more human friendly and which could have significant market potential.

It has taken 25 years of research for Shadow Robot to get to this position, which is best described as a small-scale company with technological leadership, with considerable potential but limited resources. Nevertheless, it has outlasted all the apparently more credible government-funded and university robot-building projects from the late 80s and early 90s. "Over the years we'd have people saying, 'There's no way you can do this'," says Rich Walker. "Five or 10 years later we'd find the department wasn't there any more or weren't doing robotics. And we'd say, 'It's no wonder you can't do big projects because organizations don't live long enough in the UK to do anything long term'." Shadow, he says, survives because it has low overheads and no large production organization to maintain: 90% of its staff are engineers.

It is noteworthy that in 2006 the company made an appearance on the BBC TV programme *Dragon's Den* – a reality show with entrepreneurs pitching to real business angel investors. During the summer of 2006 the company was overwhelmed by enquiries for its Dextrous Robotic Hand, and were actively seeking further investment. Increased demand meant the company needed to increase its capacity with more capital investment to develop the manufacturing end of the business. However, the BBC's Dragons were reluctant to invest in a company focused on research and development, and they felt that The Shadow Robot Company was ideal for government sponsorship. "I'm not confident you have a mass product," said Mr. Bannatyne.

Despite the potential, the company has not yet attracted significant investment, aside from sales of its products, other revenue has come from participation in research projects in EU Framework programmes, notably in one involving the European Space Agency. In 2010, the company received undisclosed funding from the Ministry of Defence to develop a robotic hand to help defuse roadside bombs.

Open source platforms

As we have seen elsewhere in the sector, the use of open source software and hardware platforms is seen as fundamental. Shadow Robot joined the ranks of Willow Garage, iRobot, and many other developers running the Robot Operating System (ROS). The company was already supporting the world robotics community: their Dextrous Hand was made available for other researchers to purchase in a development kit. Now it's not necessary to buy a Dextrous Hand to help develop it. Simulations for the device can be run using other ROS software. Programmers can work on the hand without buying a physical copy of it. This should accelerate the rate in which new software for the device is created.

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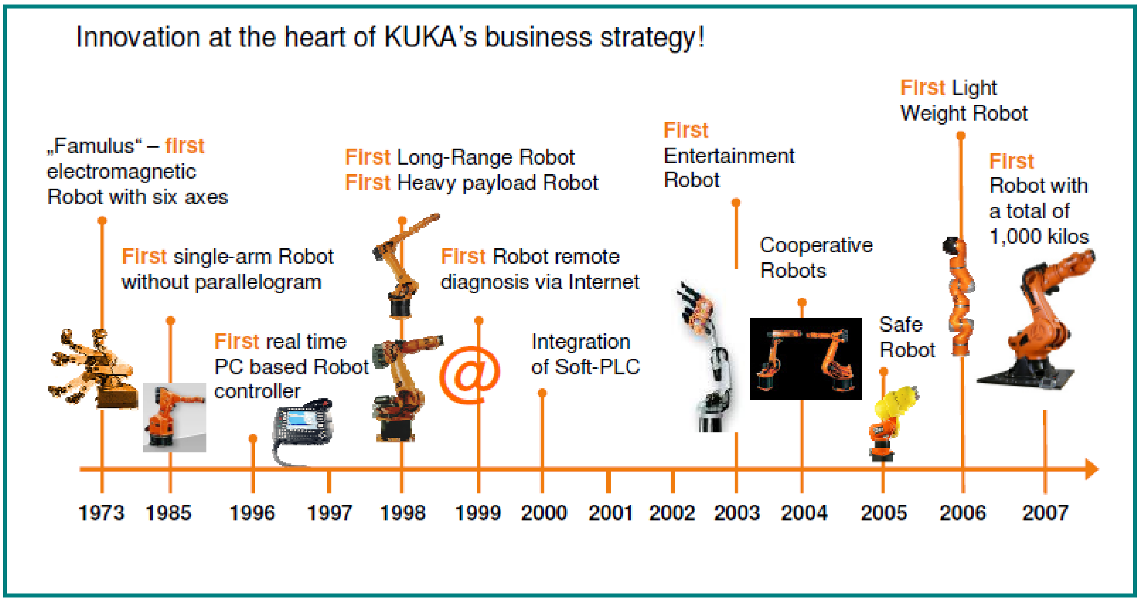
KUKA Roboter

KUKA Roboter GmbH is the descendent of a machine tooling company founded in 1898 in Germany. Today KUKA Robotics is one of the world's leading producers of industrial robots for a variety of industries ranging from automotive and fabricated metals to food and plastics. It is an example of innovation within a medium/large company at a world level. KUKA is headquartered in Augsburg, Bavaria and has over twenty subsidiaries worldwide, including the USA, China, Japan, Korea, Taiwan, India, Canada, Mexico, Brazil, and most EU countries. It has some 5,990 employees and revenues of €1.079 billion for an operating income of €24.8 million (all FY 2010). The company belongs to the publicly traded KUKA AG. KUKA industrial robots are used for robot-assisted production by companies such as: GM, Chrysler, Ford, Porsche, BMW, Audi, Mercedes-Benz, Volkswagen, Ferrari, Harley-Davidson, Boeing, PPG, Siemens, IKEA, Swarovski, Wal-Mart, Budweiser, BSN Medical, Proctor & Gamble, Hershey's, Sara Lee, Coca-Cola and others.

History

In 1973 KUKA launched the world's first industrial robot employing six electromechanically driven axes. Subsequent history is summarized below:



Source: 40th International Symposium on Robotics, KUKA presentation, Rainer Bischoff, KUKA from research to products, 12 Mar 2009

In 1996, KUKA made a major advance in its industrial robot development with the launch of its first PC-based controller, entering a new era of mechatronics for KUKA, for precise interaction of software, controller and mechanical systems. The aim of using PC-based controllers is to deliver consistently high quality for both industrial and consumer products for a wider range of sectors, taking robots into far more industrial applications, such as handling, stacking, inspecting, polishing and grinding. Further advances have been in combining machine intelligence with innovative gripper and sensor technologies to expand applications and industrial sectors. A primary objective of KUKA development work has always been to enter new markets, outside the automotive sector, particularly in logistics, plastics, metalworking, foundry, medical technology and the entertainment industry.

By 2006, the KUKA Robotics Corporation and its subsidiaries had installed some 80,000 robots. The company had become a worldwide market leader in industrial robots. Virtually all of the 80,000 robots installed in the field use the PC-based controller, making KUKA the leading PC-controlled robot manufacturer worldwide. KUKA currently offers a wide selection of advanced designs, with its range of 4 and 6 axis robots from payloads of 3 kg to 1300 kg and 350 mm to 3700 mm reach, in multiple types - palletizers, gantry, SCARAs and articulated robots. All are controlled from the common PC based controller platform.

How did KUKA achieve this market position and highly innovative reputation?

KUKA's website notes that close links between development and manufacturing are a decisive factor for reducing the development times of new products. In this context, it is clear that Germany, with one of the largest markets in the world for robots, is a highly suitable production location for KUKA. Moreover, this location also ensures optimal coordination of customer supply and support services – as over 50% of the robotics value chain is in systems integration and service. A further major contribution is from collaborative research, in major European projects funded by the European Commission but most importantly also in working with the German government agency for robotics for space applications, DLR.

The DLR-KUKA collaboration – state research institute supports private enterprise

The German Aerospace Center (DLR) Institute of Robotics and Mechatronics has about 100 scientists and engineers. It is renowned for its in-depth research activities in space robotics. In 1993 it sent ROTEX, the first remotely controlled robot into space with the Columbia space shuttle. But DLR has wider interests - surgical robotics and design of ultra lightweight arms and multi-fingered hands.

Since 2000, DLR and the KUKA have collaborated in a highly successful technology transfer. Effectively, DLR has contributed to KUKA's current position in the industrial robotics market, as the third best-selling robot manufacturer in the world, up from its former market position at number 13 or 14. In many areas, KUKA has benefited from the control algorithms, technologies and software developed by DLR, then implemented in KUKA products, for example:-

KUKA uses DLR's model-based minimum cycle time algorithms for high-speed spot welding for car assembly lines. Using DLR technology, KUKA robots move up to 30% faster, while the amplitudes of the vibrations at the end effector are up to five times smaller, and teaching time has been reduced as well.

For automatic optimal controller tuning, the process has been shortened from one week to one day by the automatic tuning procedure that DLR has developed and implemented for KUKA. Most interesting of all, this is a real technology transfer from another domain; it was originally developed for robust flight-control design problems in civil and military fly-by-wire aircraft applications, an area which is jolly alien to most robotics engineers.

KUKA has benefited from the DLR work on a robot component library, the core of all design phases.

Note also that this library is built using the open source (free) object oriented modelling language Modelica, whose model libraries cover many aspects of physical systems and most of the libraries are in the public domain.

Moreover, KUKA has extended its DLR collaboration into a hi-tech eco-system. For instance, work on sensory interfaces is being pursued for advanced applications by Amatec Robotics (http://www.amatec.de), a joint venture between two DLR engineers and KUKA and founded in 1997. Starting with minimal staff, Amatec now has over 50 employees, with a major focus being the combination of vision and force.

Note also that there has been project funding by national and local government. The KUKA DLR work was partially supported by local government administrations, specifically the Bavarian High Tech Offensive in Mechatronics, initiated and founded by the Bavarian Ministry for the Economy. KUKA and DLR have also been sponsored by the German Ministry of Education and Research (BMBF) in collaborative research projects such as PAPAS and DESIRE, Deutsche service robot initiative (see: www.service-robotik-initiative.de).

European collaborative projects have also contributed

European research projects have also been fruitful for KUKA and DLR. In the European Union project under DG INFSO, Real-time Simulation for Design of Multi-physics Systems (Real-Sim) DLR and KUKA worked together, with others to perfect methods and tools for design of new robots or variants of existing robots. This approach has advanced the robot component library mentioned above, based on the open source Modelica language. Further development took place in this international effort involving EU companies, universities, and research institutes. In the RealSim project, DLR developed a free Modelica multibody library (the download is available at http://www.Modelica.org/library), now used as a basis for the KUKA robot component library. KUKA has also participated in other major EC projects – notably SME Robot - The SME worker‘s third hand and Phreinds for a safe human-robot collaboration. The work of the RealSim project was funded in part by the EC DG INFSO's IST Programme. Moreover, there is also a crossover of people from academia to industry in such projects as highly motivated researchers often may decide to join one of the industrial companies involved. Industrial partners will often prefer academic partners with whom they have a good track record of successful cooperation. Note also that KUKA has sponsored university research in the USA. The KUKA Chair of Robotics at the Georgia Institute of Technology, held by Professor Henrik Christensen, is a further source of KUKA's future robotics developments.

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R.U.Robots

R.U.Robots Limited is a small highly specialized UK robotics systems integrator, employing skills in cognitive science to provide advanced robotic systems, some of which are designed to work alongside humans. Major areas are military, bomb disposal, nuclear inspection and decommissioning, aerospace and the food industry. R.U.Robots has recently built up expertise in food processing/handling (e.g. for biscuits) as it presents a major new area for applying robotics. This also demands multidisciplinary skills for a large range of different robot types. R.U.Robots delivers and installs these highly customized robots for the larger user but is not a product company.

Thus effectively the company has to be somewhat more than a systems integrator, as it must build certain specialized sub-systems on demand. It offers integration services for advanced robotics control systems, flexible automation, human-robot Interaction (HRI) and operator performance. These include specific subsystem engineering, prototyping, complete robotics system development, studies and assessments and also robot reconfiguration and upgrades. RUR works with leading universities and other technology providers to gather the latest and most relevant technology for each application – it sees its advantage as being able to deploy the very latest in robotics technology. In particular, the company has focussed on advanced techniques for cognitive reasoning, including vision inputs. This capability is now expanding in robotics because the technology to implement it fully has now sufficiently advanced. However, the capability for reasoning requires careful integration with the robot's activities. Such integration is complex and forms a barrier to entry of others.

Overall, systems integration is the largest segment by value of the robotics industry and so is a highly attractive market. And systems integration with cognitive systems is very different, being more complex, it takes longer to deliver successfully. RUR's key area of cognitive expertise is the autonomy of decision. In general, the market trend is towards far more autonomy in robots, which is required for the higher value activities - e.g. for inspection with navigation, and sensing then decision taking on inspection.

A most promising future area is working safely with people, the basis of a potential new segment, encompassing domestic robots for the elderly and service robots generally. The segment has yet to emerge fully. Its requirements contrast with heavy industrial robots, which are often isolated in cages. Using its cognitive science skills is where R.U.Robots sees its future, for robots working safely with people either in factories or in care services, e.g. for the aged. Such co-operative, safe working is needed if robots are to enter the home at all.

Geoff Pegman, CEO, made several observations when interviewed:

Japan seems to lead in service robots, such as care, but are trying to perfect an all-function robot, not restricting capability to just what is needed, so the results may be too expensive, overkill, and late to market. Here Europe is as good as anyone in the world today.

The USA led in industrial robotics with Unimation in 1962, under Engelberger, but lost out as the funding was too short-term. Today the USA only has Adept in industrial robots. To succeed in robotics demands a long-term investment view with development over 20 to 30 years. So only Japanese, German and Swedish firms survive at a global level in the largest robotics market segment, industrial robotics, while the USA (and some extent the UK) cannot compete. Industrial robots offers a platform to move into service robots.

The UK needs clusters, of customers as well as suppliers; R.U.Robots sees this as most useful to increase their business. Some form of support for those customers taking robotics technology for the first time would allay the fears they often see in small companies over investments in robotics.

UK universities are not fully supportive – they do not seem to be able to partner well with industry.

In the USA, the DoD and DARPA provide 100% funding for R&D up to the prototype stage, far more than is available in the UK. Having a prototype makes it a much smaller step to go to market. In contrast, in the UK, the MoD may on give limited grants of the order of up to €60k under the SBRI (Small business research initiative) scheme for a proof of concept. But the results and the full system development are then given to a very large company, so new capability in technology, jobs and innovation are never encouraged.

History

R.U.Robots was founded in 2003, but its antecedents and knowledge date back much further, to 1988 and the National Advanced Robotics Research Centre, a UK government research institute under the UK Department for Trade and Industry (DTI). In 1992 this was spun off as several companies and the key manager, Geoff Pegman led one spin-off, called UK Robotics, which was sold to British Nuclear Fuels Ltd (BNFL). In a BNFL re-organization, the robotics subsidiary was then sold off to a private engineering company, RTS, who were not interested in R&D for robotics. Eventually R.U.Robots was formed from the remains of this in 2003. The company operates with a small permanent core of only four staff but has currently 16 sub-contractors and a rapidly mounting volume of project work. Growth has been slow and organic with no external funding – the original seed capital came from the founder Geoff Pegman. Their experience of VCs has been poor, as VCs expect rapid returns, a low-risk venture and a secure exist strategy. This does not match innovative robotics, which is a long term investment.

R.U.Robots has always concentrated on the B2B market (i.e. for professional/industrial applications and defence) as it is the largest robotics segment. It sees consumer products as a smaller market currently, e.g. for vacuum cleaners and toys, with low margins, which do not compensate for a potentially higher sales volume. The consumer market is not attractive to most EU players, as it has low added value and so is only viable with high volume mass production. It is thus destined for the assembly centres of China and Taiwan, etc.

Generally there are no very useful support programmes for innovation in the UK, although the company has used national funding sources of two types:

- UK's Technical Strategy Board, for two small R&D grants (€18k and €22k)
- Tax rebates for R&D expenditure, which in the UK are a 50% allowance for internal R&D and 25% allowance for R&D for work delivered to external customers. Each year it is necessary to negotiate again with the tax authorities to receive this and to prove the validity against definitions of R&D which are narrow.

The company has also participated in European and FP7 projects. For a small company they are useful to network for marketing, in order to become known to potential customers. One such EU project is for stroke rehabilitation robots (SCRIPT - Supervised Care & Rehabilitation Involving Personal Tele-robotics).

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Robotdalen

The Robotdalen innovation programme was set up in 2003. It was funded initially by VINNOVA, the Swedish government agency for innovation. The overall aim is to create regional growth by building upon the local strong industrial and academic traditions and cooperating with all of the companies working in the robotics field. Regional growth targets for 2013 are 30 new businesses, 30 new products and 1,000 new jobs, targets which it expects to meet.

Robotdalen is now a cluster, a form of “robotics valley”, running across southern Sweden, from Orebro through Eskilstuna down to Vasteras. It provides innovation support for suppliers and users as well as all elements of the robotics value chain. Note also that it is sited in a very particular culture, that of Swedish manufacturing.

Robotdalen has introduced robots to over 170 SMEs in Sweden since it was established. Thus it is a successful incubator organization, not just nurturing robotics start-ups but introducing robots into the sector of the economy that uses them least today, SMEs. Effectively, Robotdalen has created a regional cluster of robotics development for industrial, field robotics, and health care applications, as well as logistical automation located in mid-Sweden.

The initiative has been deliberately sited to be adjacent to many of Sweden’s leading heavy machinery companies that also make robotic equipment, from ABB with its specialist robotics division to ESAB, Atlas Copco and Volvo that produce unmanned heavy carriers and trucks for mining and clean-up activities. Surrounding these large firms are the far more numerous SME suppliers who form a key part of the supply chains of these larger firms. Among them are service providers and other software specialist firms.

The Robotdalen cluster initiative has been established to strengthen the ecosystem links among all the relevant businesses, with a remit to integrate resources for knowledge, skills, infrastructure and innovation expertise, among universities, science parks, incubators, as well as local sources of finance. This follows the declared strategy of VINNOVA, and of many in Sweden, of adhering to the ‘triple helix’ model of innovation support - through the joint forces of the public sector, academia and the private sector.

Thus Robotdalen draws heavily on local universities to provide students who can work with SMEs to introduce robots, guided by a team of experienced mentors. These teams are tasked with helping SMEs to take up robots by looking at their business processes and proposing solutions. The fees for doing this consultancy work are paid for by Robotdalen, in order to stimulate the region’s competitivity.

The incubator provides innovation support to disseminate its techniques and competence across the region. Robotdalen builds up flexible teams for each innovation or integration problem, which it sees as a key success factor. It encourages and participates in R&D projects in SMEs, hospitals, and the large, multinational corporations, such as ABB and Atlas Copco, as well as the local universities of Örebro and Mälardalen. Such developments are generating international interest in Robotdalen and it has initiated collaboration with the American Automation Valley in Detroit, Michigan.

Over the last nine years, the focus has been on local systems integration, underpinned with regional university support and helping start-up suppliers and robot users. Robotdalen's programme has succeeded in mobilizing interested parties across the entire region. Major companies such as ABB, Atlas Copco and Volvo are backing the endeavour. Robotdalen's vision is to take a leading position in R&D and manufacturing for the specific sectors of industrial, field and health robotics. It also provides a valuable test bed for applications, for ABB and other suppliers.

The initiative on robots for SMEs is probably one of the most important projects in Robotdalen. Partners include ABB, Prevas, as well as the universities of Mäladalen and Örebro. More than 100 pilot studies of SMEs have been conducted to strengthen the competitiveness of the local SMEs by robotization of their production processes. In addition, this provides opportunities for students who are conducting the pilot studies to learn about specific obstacles in implementing new technologies. Going further it is supporting human capital growth through university education. Sweden's first university course in robotics is now held here. Robotdalen has co-operated with local universities to set up a Master of Engineering in Robotics course, at Mälardalen University while at Örebro University a new post-graduate school RAP (Intelligent Systems for Robotics, Automation and Process Control) has been created.

One example product is the Giraff teleconferencing robot for the elderly and disabled – the company moved to Robotdalen from Silicon Valley. There is a real market in Sweden for such care robots, not present in the USA, while support from the cluster has been highly attractive.

Robotdalen is part of the VINNVÄXT programme, organized by VINNOVA. This programme is its main source of funding, with some partial financing also from the European Commission. VINNOVA, is the Swedish Government Agency for Innovation Systems, which invests in developing Swedish regions with the aim of making them competitive on a global basis. Thus Robotdalen receives SEK10 million (€1m) annually over a ten-year project period, 2003-13, with provision of matching funds from regional actors. This equal share of sponsorship was one of the original funding requirements. Consequently Robotdalen has doubled its available funds, by maintaining close contacts with municipal and regional public administrations, who are anxious to expand employment in high technology.

The overall objective of the VINNVÄXT programme is to create 'winners' who can become internationally competitive in their respective fields within 10 years. A unique aspect of VINNVÄXT is the long time horizon. VINNOVA provides its winners with funds of up to 1.1 million euro per year for a period of 10 years. One of the cornerstones of the VINNVÄXT programme is that academia, industry and the public sector, the triple helix, collaborate and mobilize around a common strategic agenda.

Robotdalen's key strategy is to encourage participation by SME users and robot suppliers in innovation projects, reasoning that its support for ideas will lead to the commercialization of products and services. In consequence, partly encouraged by Robotdalen, economic growth in the region is already being driven by a robotics industry supplying industrial and surveillance robots usable by small- and medium-sized businesses. The hope is that robots for medical and healthcare services will also be common soon. To implement this strategy, Robotdalen has concentrated on three main areas:

- Strategic research - specifically robotics for SMEs, e.g. flexible grippers/fixtures; simplified robot programming; faster robot reconfiguration; mobile platforms.
- Industrial projects - for SME users able to exploit robotics with feasibility studies (using local university students and mentors), resulting in the 170+ SMEs being introduced to robots.
- New concepts – it has 5 new concepts aimed at rapid commercialization.

Research and development is focused on creating new business opportunities, especially for industrial robots for small and medium-sized companies, as well as in the health care field. A company can either participate in an innovation project in Robotdalen or obtain support for its own ideas.

On the manufacturing industry side, Robotdalen has supported SMEs for many applications – welding, handling etc. SME users are far less skilled in systems integration and also find reconfiguration for new production processes difficult compared to large users. Thus they need far more support, with simpler integration and reprogramming phases. There are greater barriers to SMEs becoming users, compared to large national or multinational companies, who tend to have in-house robotics skills.

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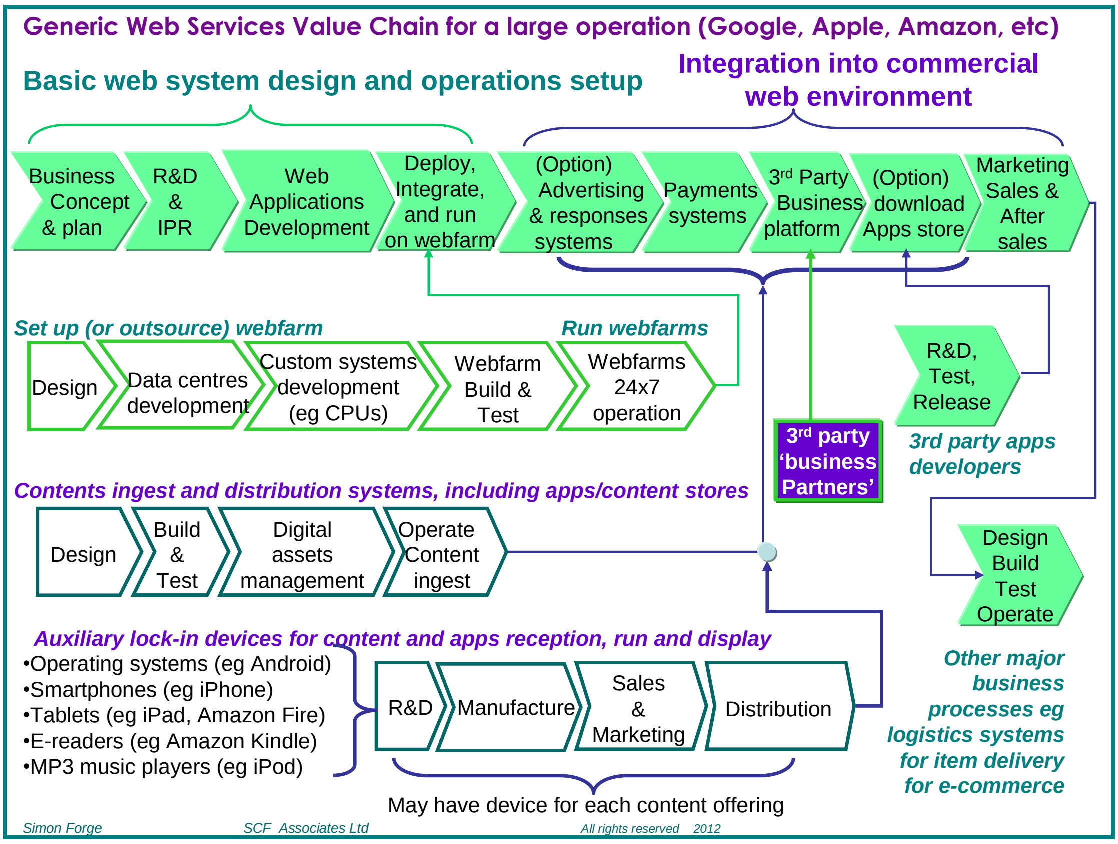
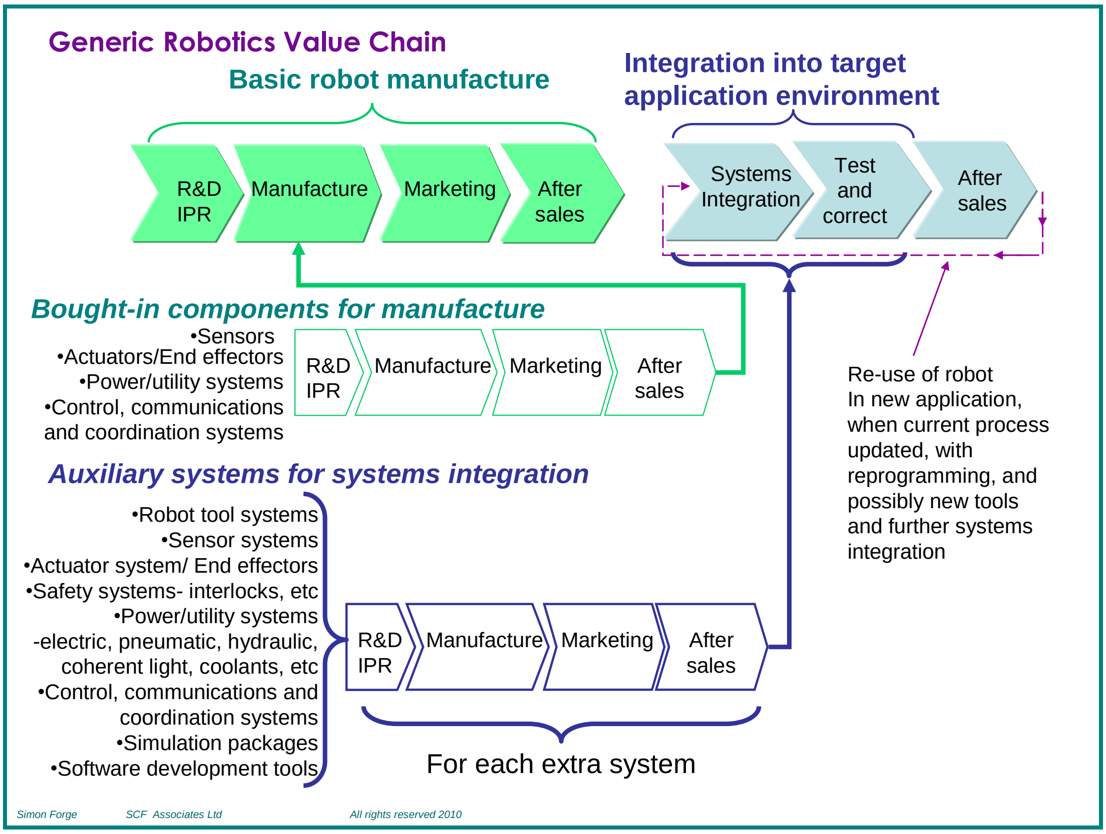
Appendix 2: The Value Chains in the Three Sub-sectors

Here we illustrate the structures in which value is created for the three ICT sub-sectors. The value chain is a useful model for understanding how a business operates, especially in a particular ICT sub-sector which has its own individual complex commercial structure. The value chain identifies the key components from a value adding perspective with their relationships and flows. An accurate value chain assessment shows what the primary activities that add value are, revealing flows of inputs such as materials, software, sub-systems and also information and added value flows. It can be used at the level of a single company or at an industry level. For a sub-sector analysis, it characterizes the flows outside one enterprise, from the start of the supply chain through the company and on into the distribution chain - which has sometimes been called the value system or value network (Porter 1985). It also highlights the dependencies and the critical path for production and the potential operational risks. Typically, it can be used to identify the true centres of profit, and loss. For instance, for robotics, the manufacture of a robot is less than 50% of the total value of an installed robot in an industrial production setting (Forge, Blackman 2010). At a subsector level, it can act as a template to identify and compare many different interacting players that form the sub-sector and its eco-system. For instance in making a consumer product such as a smart phone, assembly of the units may be the simplest activity, yet have high added value, while there may be very differing value among the components such as the display panel with its touch screen, the processor and the software such as a standard operating system. It can also indicating what business model is likely to be most successful – for instance the trend to verticalization in the web services sector from device to operating system to service as a lock-in mechanism in a web market.

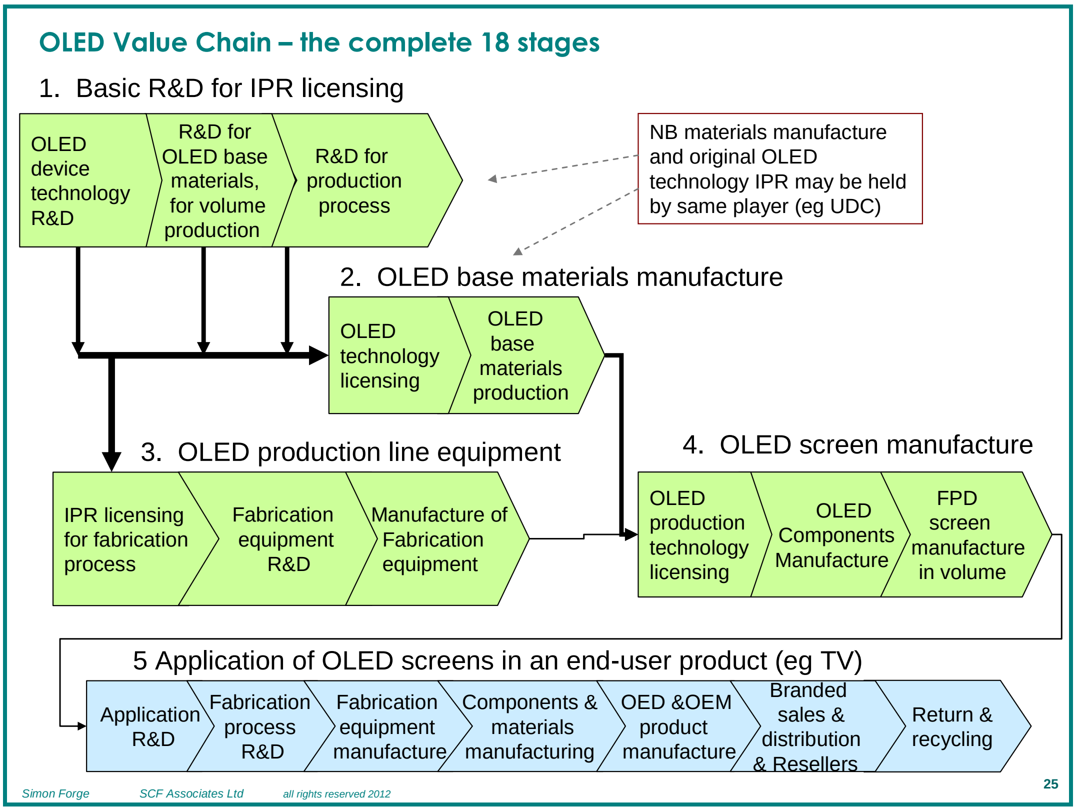
1: The Web Services value chain: web farms requires the largest capital investment



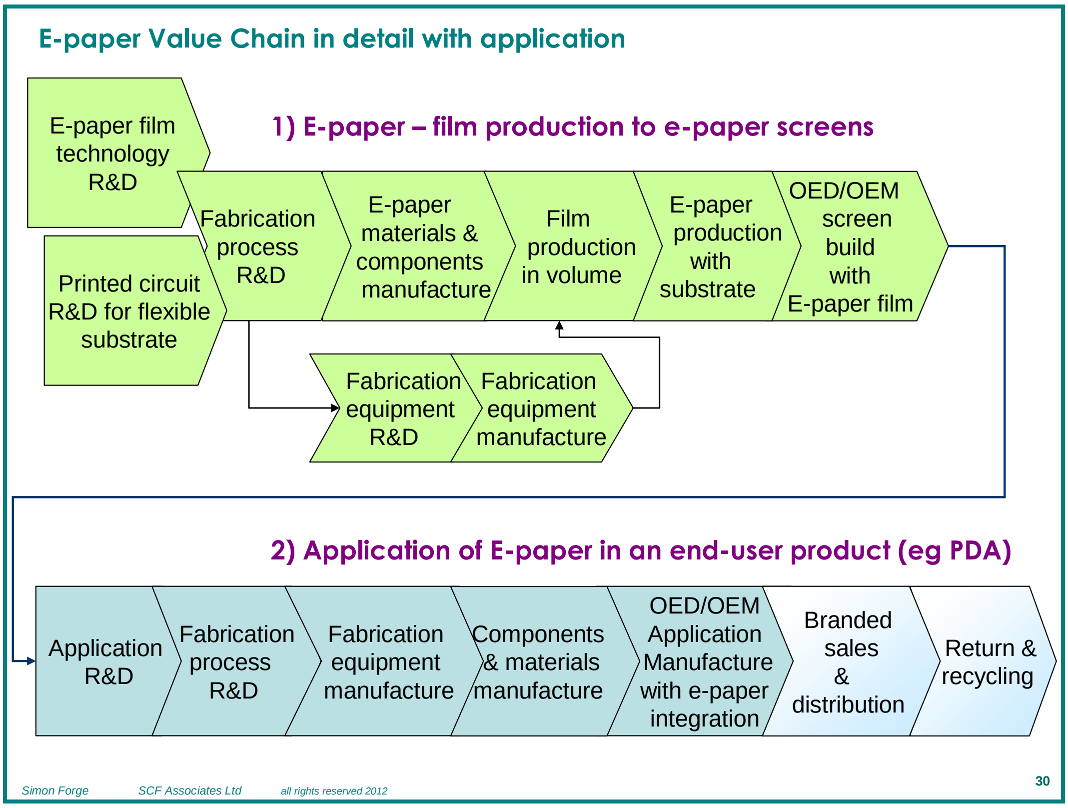
2: Robotics industry value chain – integration may be more valuable than the robot



3A: The displays industry value chain for OLEDs – full production is capital intensive



3B: The Displays industry value chain for e-paper – production of the display screen is capital intensive, with long R&D times to develop the concept and production processes



European Commission
EUR 25961 – Joint Research Centre – Institute for Prospective Technological Studies

Title: Comparing Innovation Performance in the EU and the USA: Lessons from Three ICT Sub-Sectors

Authors: Simon Forge, Colin Blackman, Itzhak Goldberg and Federico Biagi

Luxembourg: Publications Office of the European Union

2013 – 108 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online)

ISBN 978-92-79-29825-7 (pdf)

doi:10.2791/13458

Abstract
The objective of the study is to document the existence of innovation gaps between the EU and its main competitors in specific ICT sub-sectors – namely web services, industrial robotics and display technologies –and to explore the role of government policies in Europe's future needs for innovation in information and communication technologies (ICT) through a comparison with the USA and Asian countries. Our analysis shows that rather than there being a simple innovation gap with the EU lagging behind the USA, a more nuanced picture emerges in which firms in different countries have strengths in different sub-sectors and in different parts of the value chain.

A key lesson from the analysis of the three subsectors is the critical importance of higher education, particularly elite university research, and of local networks as generated by clusters. Governments can also encourage innovation through appropriate intellectual property and competition laws and, more generally, through the development of a business environment conducive to innovation. Finally, Governments can have a very important role through the funding of early-stage innovation.

LF-NA-25961-EN-N

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ISBN 978-92-79-29825-7

Publications Office