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The role of Technology and Technology-based Firms in Economic Development

Rethinking Innovation and Enterprise Policy in Scotland

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Executive Summary

This paper explores the role played by technology, innovation and technology-based firms in the economy, and the contribution of high-growth firms to technological development. We begin by defining technology and discussing the nature and characteristics of technology in modern economies. Technology development has many economic benefits that cannot all be captured in economic indicators. We define technology broadly to capture not only the equipment, software or instruments used to produce a good or service but also the (tacit) knowledge, techniques, organisational methods, etc. used to design, develop and market the products and services by businesses (and indeed the public and not for profit sector), in co-operation with other actors in the innovation system.

We consider that policy intervention that seeks to favour the emergence and absorption of new, novel, innovative technologies and products in an economy needs to consider not only the standard market failure argument, but should adopt a systems failure perspective in order to foster capabilities and incentives to diffuse technologies and innovation co-operation.

With regards to the relationship between R&D and economic growth, we note that the importance placed on "high-tech-high-growth" firms in economic development policy is due to a prevailing assumption that R&D directly leads to growth. If, as posited by Schumpeterian models, it does not, then it is not surprising that the link between high-tech firms, high-growth firms and overall economic competitiveness is more complicated than generally assumed by most policy makers.

Indeed, we observe that high-growth firms are not over-represented in high-tech sectors but occur in all sectors (which seems to go against some popular intuitions). Moreover it is difficult to identify high-growth firms before their growth episode, making policy interventions difficult. We review the literature on barriers to growth, and barriers to innovation, and identify a number of factors that hinder firms.

In this context, we discuss the 'Swedish paradox' that higher R&D expenditures do not always translate into higher growth (at least in the short-term and perhaps even the medium-term) and the 'Norwegian problem' where the contribution of innovation to wealth generation may be under-estimated due in part to industrial structure and to the specific forms of non-technological or resource based innovation occurring in the economy. We then review the evidence on R&D, technology development and innovation in Scotland. The Scottish innovation system is characterised by world-class academic research, but Scottish firms seem to suffer from a lack of absorptive capacity (required to translate cutting-edge research into wider technological progress). Scottish R&D levels are relatively low by international comparison and have not been driven in the last decade by high-tech sectors.

Oil and energy-related sectors play a considerable role for Scottish high-technology firms. University spin-offs play a role in the commercialisation of new technologies, but their role in generating economic growth and employment relatively small. At the same time, the relatively low levels of business R&D do not seem to be over-negatively, at least in the short run, influencing business productivity relative to the rest of the UK. Hence, we seem to be faced by a 'Scottish conundrum'.

To conclude, we present a number of policy recommendations. It will be difficult for policy interventions to effectively meet the challenge of boosting innovation intensity in the Scottish economy by focusing attention on a relatively limited number, by definition, of high-growth firms, high-tech firms or university spinouts. Instead, attention should be put elsewhere in the innovation system notably by supporting more collaborative projects between small and medium sized firms, ideally with a larger Scottish owned or multinational firm as a mentor. Equally, while Scotland boasts excellent academic research and significant efforts have been made to commercialise such research, the wider diffusion of new technologies to a broader base of firms could be enhanced by increasing the internal capabilities through tailored support networks or graduate placement schemes. Equally, the possibility to increase the breadth, depth and quality of technological learning at all levels of education, including initial schooling and life-long learning programmes, should be explored. Finally, boosting the self-employment rate will not help growth - instead attention should be placed on high-quality entrepreneurs, with industry experience, who start innovative businesses at a respectable scale.

Introduction

There is a well entrenched 'stylised fact' that the higher the level of investment in research and development (R&D) in an economy, the higher will be the rate of growth. This assumption, allied to the market failure argument for Government intervention, lies behind an almost across the board commitment of governments in the industrialised world (and indeed, in emerging and even developing economies) to support business R&D as well as the commercialisation of publicly funded research results carried out in the higher education or public research sectors. Hence, most, if not all, government strategies on innovation and business growth are predicated on an assumption that "technological development drives growth". This view is often expressed even more pointedly as 'high-tech drives growth'. At the same, over the last couple of decades, a holy grail of enterprise policy has become the elusive gazelle, firms that grow at exceptional rates in a sustained way over a number of years. In line with the 'technology drives growth' orthodoxy, there is a commonly held belief that such high-growth firms are, almost invariably, hi-tech or technology intensive firms.

In this context, we were asked by Scottish Enterprise to 'critically explore and unpack the role played by technology and technology-based firms in the economy'. In order to provide a foundation for future analysis and policy development, Scottish Enterprise asked for a 'think piece' (a comprehensive discussion document) that would shed light on the dynamics of technologies absorbed by firms and technology-based firms themselves, their growth dynamics in Scotland and their contribution to the Scottish economy. Hence, this paper aims to inform the future activities of business support agencies such as Scottish Enterprise via, inter alia: sectoral intervention and prioritisation, forms of innovation support, grant eligibility and claw-back criteria and the development of new policy interventions.

Accordingly, this paper examines the main benefits that arise from investing directly and stimulating other public and private investment in the development, commercialisation and exploitation of new technology and technology-based firms. The terms of reference asked us explicitly to examine 'how tangible are these perceived economic benefits in reality?'

In doing so, we have sought to unite the evidence from two parallel but inter-linked fields of research: the role of technology and innovation in driving productivity growth and economic growth; and the extent to which employment, and wealth, trends are driven by a few 'high-growth' firms in most economies.

The first section, drawing on a literature review, sets out a conceptual framework and provides a summary of the evidence on the role of technology and technology based firms in an economy.

Based on this review, the second section examines, the case of Scotland in order to explore whether the focus of Scottish innovation and enterprise policies over the last decade on supporting specific sectors and high growth and hi-tech firms (notably university spin-offs) is appropriate. The explicit assumption that a policy focusing on hi-tech has sustained higher growth is critically examined.

Given the findings of the first two sections, a final section examines the possible policy options for fostering higher economic growth through alternative policy routes.

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1. Is there a relationship between high-tech and high-growth entrepreneurial activity?

1.1 Technology, technological development and innovation

Technology, technological development and innovation are concepts and words used freely, and often without a proper understanding, in most economic development and enterprise policy papers. This section sets out a conceptual framework for the remainder of the think piece.

According to Mokyr (2008, p1) "Technology is the utilisation of natural phenomena and regularities for human purposes". Similarly, Dosi (2010) defines technology as a human-constructed means for achieving a particular end, such as the movement of goods and people, the transmission of information or the cure of a disease. In short, technologies involve the application of human intelligence to harness the laws of science for our own ends. "The fundamental unit of technology can be regarded as the technique", writes Mokyr (2008, p1), or in other words the 'routine' or the 'capability' to apply a technology. Dosi (2010) similarly, notes that the procedures and the underlying knowledge they draw upon, the physical and intangible inputs implicated, and the performance characteristics of outputs are different but complementary aspects of a technology. Since there are, of course, a number of possible techniques available for converting given inputs into outputs, the mix of inputs and outputs may vary, and hence firms will vary in their productivity levels. Hence, some firms manage to develop better techniques and are more productive than others even when applying the same technology.

However, while a technology is 'human constructed', technological progress may be not an especially democratic or egalitarian process. Mokyr (2008, page 4) writes that: "It is a small elite of original, skilled, and driven minds that drives technological progress." Furthermore, it may well be that society revolts against technological progress, due to ethical, religious, etc. concerns (e.g. GM foods, stem-cell research) or perhaps (like the Luddites) being motivated by (often unfounded) fears of labour-saving 'technological unemployment' (whereby labour is replaced by capital). Mokyr (2008, p3) concludes, somewhat pessimistically that as there are powerful forces of inertia that hinder technological progress, "most societies that ever existed were not technologically creative". This highlights the need for policy makers to see technological progress as a 'fragile' rather than an 'irresistible' mode of organisation of human economic activity. Technological development should not be taken for granted, but instead requires continual policy support.

The OECD (Frascati Manual) defines technological innovation as all activities (the scientific, technological, organisational, financial and commercial steps), including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products and processes. Therefore, technological development is wider than the research and development (R&D) process. Similarly, the OECD (Oslo Manual) argues that to identify the full range of changes that firms make to improve performance and their success in improving economic outcomes requires a broader framework than technological innovation. The inclusion of marketing and organisational innovations creates a more complete framework, one that is better able to capture the changes that affect firm performance and contribute to the accumulation of knowledge. An even broader definition of innovation includes 'hidden innovation': "the innovation activities that are not reflected in traditional indicators such as investments in formal R&D or patents awarded" that include activities such as the adoption and diffusion of new technologies (NESTA 2007, p4).

Technological product and process (TPP) innovation is only part of the answer and there is no "linear path" from research to commercial application of a technology in the form of a product, process or service. Accordingly, there is a need to understand the role of both R&D and non-R&D inputs in the innovation process and how they may be interrelated with other innovation inputs and influenced by the innovation system, in order to understand how technology can influence productivity and growth.

Moreover, since the seminal work of Chris Freeman (1988), it has been recognised that innovation is a not a 'linear process' (from the research lab to the market) but takes place and is either driven or impeded by the broader innovation system in which a company operates. Innovation and technology development are the result of a complex set of relationships among the actors in the system, which includes enterprises, universities and government research institutes. As systems are defined by components interacting within boundaries, policy should seek to address missing components, missing connections and misplaced boundaries, or what can be termed system failures.

Box 1: should policy intervention be justified by market or system failures ?

Governments traditionally rationalise their intervention in support of new technology based firms through the need to tackle a '**market failure**'. Such failures occur when market mechanisms are unable to secure long-term investments in innovation due to uncertainty, indivisibility and non-appropriability (Arrow, 1962). A market failure manifests itself in an insufficient allocation of funding to (by financial institutions) and by enterprises to risky and innovative investments.

Examples of specific 'market failures that face technology based firms, include, the so-called valley of death that discourage investors in high-tech firms during the proof of concept and early product development and testing phase of the product (e.g. in the biotech sector). The long-time to market and the obligation to 'burn' capital prior to sales beginning (if they ever do) make it likely that many firms will not receive funding from normal commercial financial institutions. Policy interventions based on the market failure approach tend to be in the form of financial support to specific firms (R&D grants or tax incentives) to address the perceived under-investment or to reduce the risk and uncertainty of investment.

In contrast, if a systems perspective is adopted, then policy-makers need to take account systems failures that may impede technology-based development even when government's provide direct financial support. The four main types of system failures (Smith 2000, Arnold, 2004):

- **capability failures**: limited ability of companies to innovation due to, for example, managerial deficits, lack of technological know-how, in-house learning processes or 'absorptive capacity';
- **institutional failures**: inadequacies in other relevant NIS actors such as universities, research institutes, patent offices and so on. Rigid disciplinary orientation in universities and consequent inability to adapt to changes in the environment is an example of such a failure;
- **network failures**: problems in the interaction among actors in the innovation system, such as inadequate volume and quality of links, 'transition failures' and 'lock-in' failures (Smith, 2000), as well as problems in industry structure such as too intense competition or monopoly power;
- **framework failures**: shortcomings of regulatory frameworks, intellectual property rights (IPR), health and safety rules, etc.. This failure also extends to social values (cultural, religious, ethical, etc.) which may reduce consumer demand for newer, innovative products (Smith, 2000).

Policy intervention based on a systems failure rationale places a strong emphasis on **tackling bottlenecks in the system** that impede firms from accessing know-how, engaging in co-operation (with other firms as well as research or specialist organisations), sourcing skilled staff and re-skilling existing staff, reforming unfavourable regulatory regime or financial market reforms, etc.

In a systems perspective, the government's role is not to promote 'individual innovation events', it is about 'setting the framework conditions' in which innovation systems can self-organise and, thereby, enhance innovation opportunities and capabilities (Metcalfe, 2005). Similarly, Rodrik (2004) argues that industrial policy is not about 'picking winners', rather it is a process whereby the public and private sector arrive at a joint diagnosis about the sources of blockages to new economic activities and propose solutions to them.

To sum up, we define technology broadly to capture not only the equipment, software or instruments used to produce a good or service but also the (tacit) knowledge, techniques, organisational methods, etc. used to design, develop and market the products and services by businesses (and indeed the public and not for profit sector), in co-operation with other actors in the innovation system.

We consider that policy intervention that seeks to favour the emergence and absorption of new, novel, innovative technologies and products in an economy needs to consider not only the standard market failure argument, but should adopt a systems failure perspective in order to foster capabilities and incentives to diffuse technologies and innovation co-operation.

1.2 How does technology contribute to growth?

Given this conceptual framework, we now examine the theoretical explanations that seek to explain how technology contributes to the economic development of a country or region. Neo-classical (the so-called Solow) growth theory assumes that the level of output is determined by the amount of available labour and fixed capital interacting within the framework of a given technology available to all and determined 'outside of the economic system'. Hence, the economy converges on a unique long-run stable growth path determined by the growth of the labour force and 'technical progress'.

From an economic development perspective, the neo-classical growth model leads to the convergence (or catching-up) hypothesis: that there should be a systematic tendency for poorer countries or regions to grow faster than richer ones, since the capital-labour ratios of the former are below the long-run optimum. Whilst such convergence does occur in the case of certain countries or regions, there is no evidence of across the board 'catching-up' (think for instance of the relative performance of the EU27 regions over time in converging to the EU27 GDP per capita average or the highly variable growth rates of the former Eastern bloc countries post 1990).

As some regions and countries manage 'structural adjustment' over time better than others this suggests that other factors (such as imperfect competition, incomplete appropriability of returns from investment, international trade interdependence) are important determinants of how much an economy will invest in technology. A second school of thought, called endogenous growth theory, does not take the rate of technological progress as a given but rather assumes that private investment in R&D is the central source of technical progress leading to increasing return to scale. In this model, total factor productivity growth[1] is due to a faster pace of innovation and extra investment in human capital. Moreover, it assumes that technology has a partly public good nature, or in others words there are technology spillovers between firms in the R&D process. Hence, appropriate government policies can permanently raise growth rates particularly if they lead to a higher level of competition in markets and a higher rate of innovation. However, empirical testing of endogenous growth theory has not entirely confirmed these predictions suggesting that there are other factors influencing growth.

A third set of growth theories introduces a much stronger role for entrepreneurial dynamics in explaining growth. Schumpeterian models assume that faster growth generally implies a higher rate of firm turnover, because a process of creative destruction generates entry of new innovators and exit of former innovators. Schumpeterian models introduce the concept of technological frontiers and distinguish between a 'frontier innovation' where a company (region/country) leapfrogs the best technology available before the innovation and 'imitation' innovation: a technological activity whereby the country or sector catches up to a global technology frontier which represent the stock of global technological knowledge available to innovators in all sectors of all countries. This is an important distinction since within most sectors in any national or regional economy the balance of technological development activity is likely to be through imitation, or in other words through companies integrating knowledge (technologies) produced elsewhere to ensure they remain close to the global technological frontier and hence competitive.

From a policy perspective, Schumpeterian theory assumes that 'innovation frequencies' determine a country's growth path endogenously based on incentives (and disincentives) faced by prospective innovators. These frequencies depend upon the institutional characteristics of the economy such as (intellectual) property rights, the strength of the financial system, and also upon government policy.

The Schumpeterian approach has thus a number of important policy implications. Firstly, government intervention to support R&D and innovation will be ineffective if the basic micro and macro-economic conditions for innovation-based growth are not in place (Aghion (2006) has argued that). These conditions are: i) competition policy favouring market entry and exit, ii) investment in higher (and indeed lifelong) education, iii) reform of credit and labour markets and iv) a counter-cyclical fiscal policy. Secondly, the policies (and institutions) that favour imitation are not the same as those that favour leading-edge innovation (Aghion et al, 2011). A country that is far from the global technological frontier will maximise growth by favouring institutions that facilitate imitation, however when nearer to the technological frontier, the country will have to shift from imitation-enhancing institutions to innovation-enhancing institutions in order to sustain a high growth rate.

We conclude that the importance placed on "high-tech-high-growth" firms in economic development policy is due to the prevailing assumption that R&D directly leads to growth. If, as posited by Schumpeterian models, it does not, then it is not suprising that the link between high-tech firms, high-growth firms and overall economic competitiveness is more complicated than generally assumed by most policy makers.

[1] Technical progress is measured by total factor productivity (TFP). TFP is the share of overall growth that cannot be accounted for by increases in quantities of inputs alone. In other words, TFP measures improvements in efficiency with which available inputs are used.

1.3 Evidence on technological development and growth

If as set out above, technology, and more generally innovation, plays a critical role in fostering and increasing economic development potential, there is a need from the policy perspective to understand the types of benefits that can accrue from both public and private sector investment into technology. Such benefits can include new processes/products, knowledge spillovers, human capital formation, productivity growth, reduced environmental damage or resource depletion, etc. Technology may improve job-satisfaction and life-satisfaction in ways that cannot be easily measured in economic terms (e.g. improving work standards, removing 'drudgery', reducing accident rates, etc).

Most EU, and indeed OECD countries, have set themselves targets for increasing investment in R&D (both public and private) with a more or less explicit assumption that there will be benefits from such investments. Scott et al. (2001), outlined six channels of economic benefit from research: 1) increasing the stock of useful knowledge; 2) training skilled graduates; 3) creating new scientific instrumentation and methodologies; 4) forming networks and stimulating social interaction; 5) increasing the capacity for scientific and technological problem solving; and 6) creating new firms. The section does not examine each of the routes in details but rather considers the role of technological development, and more broadly innovation, in driving economic growth and the extent to which technological development is a driver of new firm creation and growth.

As noted above, economic growth theories suggests that investments in R&D are a necessary, but not sufficient, condition for increasing TFP. Indeed, the empirical evidence is not conclusive. The NBER (1999), for instance, has argued, that the decentralised economy typically under-invests in R&D relative to what is socially optimal; a finding with which Jones and Williams (1998) concur, since they argue that conservative estimates suggest that optimal R&D investment is at least two to four times actual investment. This perceived 'under-investment' may help explain why the NBER (2004) found that R&D makes a relatively minor contribution to productivity growth. In contrast, the OECD (2001) found that business expenditure on R&D (BERD) is significantly positively correlated with multifactor productivity (MFP) growth[2]. The effect is larger in countries that are intensive in business R&D, and in countries where the share of defence-related government funding is lower. In addition, there is evidence that there has been a growing impact of BERD on MFP over time.

Since the early 2000s, some small north European countries, such as Estonia or Ireland, have achieved rapid growth in BERD, from low levels, allied to high economic growth (at least up to the financial crisis). In both cases, the factors driving growth were partly external: the EU's Structural Funds led to a massive boost in public investment in R&D and public support for business R&D while inward investment firms account for a significant share of innovation activity. However, as can be seen in box 2, evidence from Ireland suggest that domestic firms also improved TFP faster as a result of the increased R&D. In policy terms, the key may be to develop strategies to absorb industrial learning in the local economy

Box 2: business expenditure on R&D and productivity growth in Ireland

Ireland's BERD has been growing strongly (a 78% increase between 2001 and 2007, from €900m to €1.6bn) it still lagged below the 2007 EU15 and OECD averages of 1.2% and 1.6% of GDP respectively. In 2007, €0.9bn was spent on R&D in manufacturing related activities, whilst €0.7bn was spent on R&D in services related activities. In 2007, the key performing sectors in company R&D in Ireland were Electrical/Electronics, Computer and Related Activities, Chemicals, Instruments, and Food Beverage and Tobacco. These categories are underpinned by the following industries – ICT Hardware, Software, Pharmaceutical, Medical Devices and Food.

There have been very few studies based on Irish data, however Gorg and Strobl (2005) investigated whether there is any link between R&D and plant level productivity for Irish firms. They find that own R&D activity of domestic exporters is positively linked to their total factor productivity. This is consistent with the international literature which finds a strong positive relationship between the stock of R&D and productivity at the firm level (Griliches, 1998).

If it is true that R&D investment boosts productivity, how can it be that over the last couple of decades, some countries invest more than others in R&D and yet have lower growth? Leydesdorff and Wagner (2009, p357) observed "Japan, Sweden and Finland, for example, spend more than 3% of GDP on

[2] Guellec and Van Pottelsberghe de la Potterie (2001), R&D and Productivity Growth : Panel Data Analysis of 16 OECD countries, OECD Economic Studies No. 33, 200/11.

R&D, while other nations with comparable levels of welfare (e.g. the UK, the Netherlands, and Norway) spend less than 2%." Hence, higher levels of R&D do not automatically translate into higher growth or higher levels of income per head.

Sweden in particular has been singled out as a country with high and above average R&D expenditure and below average growth[3]. This paradoxical phenomenon is sometimes referred to as the "European Paradox" (Dosi et al 2006) or the "Swedish paradox" (Ejermo and Kander, 2011)[4]. At the other end of the spectrum, another Nordic country, offers an alternative paradox. On the one hand, Norway is among the most wealthy (partly due to more careful management of oil revenues than has occurred in the UK[5]) and productive economies in the world. On the other, it does not rank highly in international comparisons of innovation and business R&D. The seeming mismatch between innovation effort and economic performance has been referred to as the '**Norwegian puzzle**'.

However, as noted above, such paradoxical results may be not so odd. In the case of the 'Swedish paradox', even if R&D does generate more patents, prototype or ideas, there is a non-trivial link between these new 'technologies' and economic growth. This link is entrepreneurship – entrepreneurs are needed to take new technologies and new ideas and apply them to commercial ends (Audretsch and Keilbach, 2008). Interestingly, the results of the global entrepreneurship monitor (GEM) 2012 for Sweden refer to an alternative Swedish paradox[6]. The 2012 survey found that Swedes perceive good opportunities to start a business, but very few actually do, and among those who start a business growth aspirations are modest. This conclusion is very much in line with the Schumpeterian theory that it is 'creative destruction' not technology investment per se that drives growth. Indeed, Braunerhjelm et al (2010) found that it is primarily entrepreneurial activity which influences growth and that the importance of entrepreneurs in driving growth increased in the 1990s.

Four explanations have been advanced for the Norwegian puzzle (OECD 2008, Koch et al, 2008) and a number of them are relevant for the Scottish case that we explore in the next section:

- Innovation activities in the Norwegian economy are not fully captured by common innovation indicators. Non-R&D-based innovation seems to underlie the productivity performance of the Norwegian services sector. Moreover, many Norwegian firms focus on incremental process innovation instead of radical product innovation.
- The Norwegian business sector is dominated by small businesses in sectors with comparatively low measured innovation and R&D activity. Industry by industry, R&D spending in Norway is at or above the OECD average. If all OECD countries had the same industry structure, Norwegian industry would be the 11th instead of 17th most R&D-intensive country in the OECD. The same effect is not visible for the UK, which remains in 12th place in the adjusted rankings (OECD 2011).
- The impact of the Norwegian model on innovation is underestimated. There are many sources and drivers of innovation, and some are not easily captured by available quantitative indicators. In Norway, there is a belief that factors such as employees trust and participation, low wage dispersion and a high level of acceptance of technological change in the labour force, as well as strong welfare schemes, have crucial importance in our ability to adapt and innovate. A specific socio-cultural framework combined with the openness of the economy and disciplined macroeconomic policy are seen as major "non-technological" contributors to strong economic performance.
- Innovation activities in the petroleum industry are under-reported (as is also the case for the Scottish petroleum industry; see NESTA 2007). The Norwegian petroleum sector performs large

[3] For a good, succinct discussion of Swedish GDP growth trends since 1993 and illustrative graphs see : http://www.ekonomifakta.se/en/Facts-and-figures/Economy/Economic-growth/GDP/

[4] Ejermo and Kander (2011) argued that the existence of a 'Swedish Paradox' depends upon which years of Sweden's recent history are taken into consideration. They looked at the relationship between R&D and patenting activity across a number of sectors, and did not observe that Swedish R&D is becoming any less efficient at generating patents, in fact, they observed (p1107): "data suggests that Swedish firms produced an average of 0.11 patents per million US dollar of R&D expenditures in 1985 and improved to 0.15 patents per million US dollar in 1998."

[5] http://www.ft.com/intl/cms/s/0/b6e0e756-e87c-11e1-8397-00144feab49a.html#axzz244CD2aqT

[6] http://eng.entreprenorskapsforum.se/2012/06/19/global-entrepreneurship-monitor-national-report-2012/

offshore development projects, involving many knowledge-intensive engineering activities. These may actually involve substantial development and innovation efforts. However, it is likely that the sector underreports these activities in innovation and R&D surveys. The reasons are unclear, but part of the explanation may lie in tax-related or accounting-related issues or that R&D and innovation surveys tend to be orientated towards manufacturing and less towards services or resource-based activities.

Scotland appears to be a mix of the two paradoxes: the Swedish model with a strong higher education research sector but without the Swedish owned multinational industrial 'powerhouses' which helped to drive industrial innovation; and the Norwegian paradox where innovation may be under-estimated due in part to industrial structure and to the specific forms of non-technological or resource based innovation occurring in the economy.

However, as will be discussed below Scotland's growth record, which has been broadly similar to that of the UK as a whole in the last decade[7], is weaker than either of the Nordic cases. Hence, rather than a paradox or a puzzle, we seem to be faced by a 'Scottish conundrum'.

This is not to say that the R&D intensity of an economy is a trivial issue. Ejermo et al (2011) disaggregate the R&D-growth paradox across sectors, and observe that the sectoral disaggregation goes a long way to explaining the paradox. Fast-growing sectors are especially prone to decreasing returns to R&D. Slow-growth and declining sectors do not experience decreasing returns to R&D, perhaps as they are seeking out new products to reverse their growth cycle, however. The R&D-growth paradox therefore does not seem to be a generalised disease of European innovation systems, but rather a difficulty affecting high-growth sectors.

At the firm level, Stam and Wennberg, (2009) found that the effect of initial R&D on high-tech firm growth is through increasing levels of inter-firm alliances in the first post-entry years. R&D efforts enable the exploitation of external knowledge. Initial R&D also stimulates new product development later on in the life course of high-tech firms, but this does not seem to affect firm growth The results of their analysis show that R&D matters for a limited but important set of new high-tech and high-growth firms, which are key in innovation and entrepreneurship policies. Similarly, Ortega et al. (2010) found that business R&D investment is more effective in the high-tech sectors.

Such findings should be taken into account in design policy measures (subsidies, fiscal incentives, etc.) in support of business R&D. So rather than distinguish between 'high-tech' and 'low-tech' sectors, the key issue in ensuring an economy is using and developing technology optimally is the capacity, or technological competence, of firms across sectors to integrate technologies. Indeed, Lee (2010) notes that firms with low technological-competence-enhancing capability tend to follow a convergent growth pattern in which growth gradually declines, while firms with high technological-competence-enhancing capability tend to exhibit either a sustained or a vicious growth pattern depending on the initial size of their technological knowledge stock.

In short, the way in which technology drives growth is more complex and it is not enough for policy-makers to understand the dynamics underlying the R&D activity of a small, if important, subset of high-tech firms and sectors in the average economy. This conclusion is summed up nicely by the UK Department of Business, Innovation and Skills (2011) in the background report to the 2011 UK Innovation and Research Strategy for Growth:

> *High tech manufacturing sectors are, in themselves, small. A policy focus only on these sectors therefore excludes a very large part of the economy. High tech activities mainly produce inputs that are used elsewhere – so the success of high tech industries, and their impact on productivity, depends on the extent to which they are adopted by other, lower-tech, industries. (BIS, 2011).*

Clearly the capacity to increase the technological competence or absorptive capacity of a broader range of firms in an economy is closely linked to the availability of skilled people (the second route); but also

[7] http://www.scotland.gov.uk/About/Performance/scotPerforms/purpose/economicgrowth

increasingly in an age of 'open innovation' (Chesbrough, 2003) the extent to which businesses are able to co-operate with other businesses and other agents in the innovation system (universities, public research and technology centres, etc.).

The role of the university sector in contributing to the creation of new knowledge and technologies (through scientific research) is multi-faceted (BIS, 2011, pg. 81-84 provides a good summary) but should not be over-estimated in terms of a direct effect either. In particular, the spin-off or patenting, which are observable and hence observed forms (following the principle of "looking under the lamp-post") are not necessarily the most important routes (see BIS (2011) and Scottish Enterprise 2012). Perhaps more critical is the role of universities in developing and attracting (notably international 'talent') people in(to) a national or regional innovation system. If as we argue above, the benefits of technology can only be captured if firms in the innovation system have high technological absorption capacities, then the skills for innovation required are technological but also of an organisational, managerial and marketing nature. These 'soft' skills are increasingly complementary to technical skills and necessary to innovate successfully. Indeed, there has been a steady rise in skills needed across most jobs over the last decades (BIS, 2011).

A final, and increasing important, issue in terms of optimising within a regional or national innovation system the benefits of technology development and innovation activity are the ways in which technology flows occur through foreign investment (technology diffusion to subsidiaries, etc.) and innovation activity is affected by the internationalisation of corporate R&D (or again more generally innovation). Pavitt (1998) talked about how national systems of innovation are under increasing strain, because of emerging imbalances[8] between what the science base has to offer, and the demands of the technology system. A decade later, the OECD found that in most countries the shares of foreign affiliates in total R&D manufacturing expenditure are higher than their shares in total manufacturing turnover, suggesting that R&D is nowadays more internationalised than production.

Moncada et al (2011) provide a good summary of the trends in internationalisation of R&D pros- and cons of this 'globalisation of corporate R&D on both the host country and the home country. Scotland, as a country with a strong scientific potential is potentially well placed to attract 'mobile' R&D centres given the predominant 'asset augmenting' strategies of large foreign multinationals. However, the picture is not clear cut, since, as AD Little (2005) noted the UK R&D system is already generally more internationalised than comparator countries and this contributes to an increasing dependence on foreign funding of R&D. Indeed, Moncada et al (2011) caution that from a policy viewpoint there is a need for a cautious and selective approach in inward investment support to distinguish those firms mainly driven by knowledge intensive strategies.

1.4 Hi-growth firms and public policy: rethinking the basics

1.4.1 The characteristics of High growth firms and their impact on economic growth

Since the highly influential findings of David Birch (1979), it is well-known that a minority of firms create most jobs. Storey (1994) summarises the evidence by suggesting that 4% of firms create about 50% of jobs. Henrekson and Johansson (2010) surveyed the literature more recently, and came to similar conclusions. Such findings have created a strong policy focus on 'high-growth firms (HGFs). The main interest in HGFs seems to be from an employment creation perspective. However, other rationales for motivating support for HGFs have also been advanced, such as innovation and productivity growth.

Yet for policy makers seeking to intervene and support such firms, the picture is not so clear cut. Firstly, in terms of employment creation, it is notoriously difficult for public agencies to pick out HGFs ex ante and it is often hard to see what additionality there is for such government intervention (we need to consider the counterfactual: what would have happened in the absence of these policies?). In countries where unemployment is not a significant issue, the longer-term employment rate may be

[8] According to Pavitt these imbalances reflect the combined effects of (1) the liberalisation of international exchanges, (2) uneven rates of national technological development, (3) increasing pressures of competition, (4) the increasing range of fields of potentially useful technology.

more relevant and in this case an emphasis on productivity growth, which keeps firms internationally competitive, may be more relevant.

We should also bear in mind that, were a policy intervention targeted towards high-growth firms (HGFs) put in place, it would become even harder to identify HGFs ex ante, as non-HGFs try to mimic HGFs in order to qualify for HGF benefits.

The link between HGFs and innovation is often suggested (see the box below), yet many innovative firms don't grow. In particular, many university spinouts, often thought of as a prime source of HGFs, create few jobs (Harrison and Leitch 2010), even if they are high-tech. Moreover, one of the most basic 'stylised facts' of HGFs is that they occur in all sectors (Henrekson and Johansson, 2010) and not just innovative (hi-tech) ones, so there is no clear association between innovation and HGFs. NESTA (2011) provide case studies of HGFs, such as Brompton bicycles, which can be described as a mature-technology firm.

Box 3: Should we expect that high-growth firms are high-tech?

'True entrepreneurship' is claimed to be about high-growth firms, and entrepreneurship is also often claimed to be about innovation. For example, Dennis (2011, p99) defines entrepreneurship in terms of being innovative - "entrepreneurship, by definition, is innovative."

Henreksson (2005: p439) and Reynolds et al (2005 p223) define entrepreneurship in terms of subjective growth ambitions. Bottazzi and Da Rin (2002, p235) and Avnimelech and Teubal (2006; p1477) confine 'start-ups' to high-tech industries.

The ideal-type for an entrepreneurial firm is therefore to be high tech and also to display a high growth record. Audretsch (2007, p65) writes that "entrepreneurship is the missing link between investments in new knowledge and economic growth."

Policy makers are interested in HGFs (from an employment creation perspective) and also in investing in high tech sectors (for reasons of capability development as well as a possible job 'multiplier' effect (cf Moretti 2010, Moretti and Thulin 2012)). Putting the two together, high tech HGFs would be especially desirable.

The interest in high tech HGFs is illustrated by recent policy interest in 'Yollies' (Veugelers and Cincera, 2010) - young leading innovative firms - that is, young large high-tech firms such as Microsoft, Apple, Google, Skype, Facebook, Genentech, etc. Given the academic focus on high tech HGFs, it is nonetheless surprising that HGFs are not over- represented in high tech sectors. Henrekson and Johansson (2010) survey the literature on HGFs and observe that HGFs are not over-represented in high tech sectors.

Mason and Brown (2012) focus on high tech HGFs. They write (on page 2): "A key assumption amongst policy-makers is that high growth firms (HGFs) are dominated by TBFs. [Technology Based Firms] ... The reality is that the representation of technology based firms in the population of HGFs is on a par with their proportion in the economy – and some studies suggest that they may even be under-represented."

If we assume that the main driver of firm growth is some sort of superior firm-level capabilities, where 'better' firms will grow faster, then it is natural to assume that high-growth firms will also be high-tech, or more innovative, or at least, have better routines and capabilities than their slow-growth counterparts. The reality of firm growth suggests, however, that firm growth is essentially a random process, with innovation having only a limited effect on firm growth. In reality, high-growth firms are not exclusively high tech but are found in all sectors. It would be better to view high-growth and high-tech as being distinct.

Thirdly, do HGFs bring about productivity growth? This is under-researched, but the available evidence does not suggest so. Theoretical work (Penrose, 1959) suggests that fast-growth firms have lower productivity because they are too busy focusing on growth projects to keep operating costs down. Empirical work is not clear-cut, but at least we can see that high growth is not strongly associated with productivity growth.

The emergence of new HGFs may also lead to structural change in an economy. A HGF may lead to the rejuvenation of a previously declining industrial sector or more likely engender the 'creative destruction' associated with Schumpeterian industries (Perez, 2010). Perhaps surprisingly, this is not often explicitly mentioned as a reason for supporting HGFs. Nevertheless, there is some tentative evidence that a high number of HGFs is a sign of subsequent industry growth (Bos and Stam 2011).

As a final point, it is worth asking why policy should focus on HGFs rather than on other groups of firms, such as exporting firms. Exporting firms generally tend to have high levels of productivity. Jobs created by exporting firms can be considered to be high-quality jobs. More generally, Bernard et al (2007, p105) write that: "Across a wide range of countries and industries, exporters have been shown to be larger, more productive, more skill- and capital-intensive, and to pay higher wages than non-exporting firms. Furthermore, these differences exist even before exporting begins."

With exporting firms, there is a certain ‘trigger point’ which constitutes an opportunity for intervention – the decision to prepare for entry into export markets. (Trigger points in the growth paths of HGFs are less easy to identify.) Moreover, exporting firms can be clearly identified, there is a clear direction for intervention, and the benefits of exporters are clearer than the benefits of HGFs. Exporting firms may benefit regions by generating additional jobs in the non-traded local services sector (such as waiters, hairdressers and doctors) through the ‘local multiplier’ effect (Moretti and Thulin, 2012). HGFs *per se* are difficult to pick out, and furthermore it remains to be seen whether HGFs are really ‘better’ than non-HGFs in a number of dimensions – quality of employment (in terms of benefits, working conditions, pay, and job security), profits, productivity, quality of goods, etc.[9]

Given the difficulties in identifying HGFs ex ante, we caution that a policy intervention that targets HGFs might not be very effective at picking out HGFs. Firm growth is generally viewed as a random walk (Gibrat, 1931; Geroski, 2000), and the probability of experiencing sustained above-average growth is about the same as the probability of experiencing a string of ‘heads’ when flipping a coin (Coad et al 2012) – that is, the random factor is predominant. In this context, HGF policy might be as difficult as setting up a policy for the benefit of everyone who enters a casino and will roll a few sixes on a die.

The paradox is that while it is not easy to identify which firms will become high-growth firms, it is much easier to identify firms which will definitely ***not*** become high-growth firms. The analogy would be distinguishing between individuals who have bought a lottery ticket (i.e. have a chance of ‘winning’) and those that have not bought a lottery ticket (no chance of ‘winning’). Firms that have a chance of winning can be identified by looking at a number of their characteristics, such as founder’s education, sector, venture capital investment, patents, business plan, etc (Shane 2009, Lerner 2010). Although it is difficult to pick out which firms will be HGFs, nonetheless it is easier to identify a subset of firms that will never become HGFs (Shane, 2009), such as those ‘lifestyler’ small businesses who would rather avoid any problems associated with growth. These latter firms could be excluded from benefitting from HGF policy.

1.4.2 Reviewing the evidence on Scottish high-growth firms

The main sources of information on HGFs in Scotland can be found in Mason and Brown (2010 and 2012; see also Brown and Mason (2010) for a summary). Mason and Brown (2010) observe that there are 825 HGFs in Scotland between April 2006 and April 2009. An appropriate starting point would be to recognise that “the single most striking observation [is] the heterogeneous nature of HGFs.” In agreement with the literature, they find that HGFs are present in all sectors – however, they seem to be particularly numerous in Services but under-represented in High-tech sectors. Most of these HGFs are based around Scotland’s main cities: Glasgow, Edinburgh, Dundee and Aberdeen. Most are private firms, many (39%) are foreign-owned, and a minority are true ‘gazelles’ in the sense of being less than 5 years old.

The findings in Mason and Brown challenge a number of preconceptions about HGFs. First, they are not exclusively found in high-tech sectors, but instead they seem to be relatively scarce in high-tech sectors. This highlights that high-tech firms may have difficulties growing or may simply lack growth ambitions or growth prospects. Second, HGFs are not small firms, Mason and Brown observe that medium and large-sized firms dominated the Scottish HGF population. Third, HGFs are not young firms, few are less than 5 years old (although most are younger than 25). In contrast to the existing literature base emerging from other countries, however, they highlight that Scottish HGFs are relatively heavily influenced by public policies and government legislation (p59). "The majority of HGFs have received public sector assistance at some point in their development. However, much of this has been on a relatively small scale." (Brown and Mason 2010, p74).

This latter finding prompts Mason and Brown (2011) to think about good public policy for HGFs. It would seem that the literature often fails to provide practical advice to policy-makers on how HGFs

[9] Whether or not HGFs are better than non-HGFs in these dimensions is still not known, and would benefit from further research. See however Coad et al (2011c) who investigate which individuals are more likely to be hired by HGFs. HGFs are observed to be more likely to employ young people, immigrants, and individuals with longer unemployment periods, thus playing a complementary role in labour markets with firms seeking higher-quality employees.

can be supported. Mason and Brown (2011) argue that HGF policy often targets high-tech sectors, which might be misplaced given that HGFs occur in all sectors, not just high-tech sectors. Certainly, on paper, high-tech HGFs are twice as attractive in the sense that they create jobs through high-productivity economic activity. However, non-high-tech HGFs also play an important role in the economy because they create a large number of jobs. For example, Scottish HGFs can be expected to play a leading role in reaching the goal mentioned in Scottish Government (2011) of "an ambitious target to deliver a 50% increase in exports by 2017" (page 8).

Following on from their findings that HGFs are found in all sectors (not just high-tech sectors), Mason and Brown (2012) focus specifically on HGFs in high-tech sectors. They observe that (p. 66): "The majority of firms (74%) reported obtaining various forms of public sector funding." In this respect, Scotland seems to be doing better than other countries in terms of providing support to HGFs. Furthermore, HGFs can be found in low-tech sectors, where innovation is less visible (in terms of standard indicators such as R&D and patents) but nevertheless this 'hidden innovation' has considerable economic value (Mason and Brown, 2012). For example, the oil production sector, based in Aberdeen, engages in the application and development of high-technology techniques for exploration, although these are not classified as R&D in conventional sources such as the OECD Frascati manual (NESTA, 2007). Mason and Brown (2012, p60) observe that around a third of Scotland's larger technology-based firms were related to the oil or energy sectors.

1.4.3 University spinoffs: do they drive economic development?

Research into innovation has often been implicitly based on what is known as the 'Linear Model' or the 'science push' approach: whereby innovations come about first with university basic research and scientific publications, then applied research (R&D), then patents, and then commercial innovation. On the basis of this framework, it is natural to suppose that university research will lead to high-tech firms, commercial innovation and economic growth. There have been a number of criticisms of the linear model, however, often arguing that the process is not linear because there are many feedbacks from commercial technologies to basic research. Indeed, many technologies (such as aircraft) began operation before the underlying scientific principles were understood.

The linear model suggests that university spinoffs should be important in terms of commercialising scientific advances and leading to economic growth. The reality is that the linear model is limited, and that university spinoffs do not generate huge economic benefits. The available evidence seems to be tainted by ideology rather than a frank appraisal of the evidence. Harrison and Leitch (2010, p1245) write about the 'Entrepreneurial University' that: "these arguments remain based on advocacy rather than evidence and analysis." Indeed, Reid et al (2011) noted that it takes about 90 million dollars of research spending to generate one spin off on average from the top 200 US universities. They estimated the figure was similar for the UK's top universities.

Interest from policymakers in university spinoffs has grown in recent times for a number of reasons. Perkman and Walsh (2007, p260) identify "various trends: an increasing patenting propensity by universities ... growing university revenues from licensing ... increasing numbers of university researchers engaging in academic entrepreneurship ... a growing share of industry funding in university income ... the diffusion of technology transfer offices, industry collaboration support offices and science parks." Interest from academics has also grown rapidly in recent years (Rothaermel et al, 2007).

Audretsch and Keilbach (2008) identify university entrepreneurship as the missing link between successful innovation (as measured in R&D or patents) and economic growth. However, they note that policy measures to start high-tech entrepreneurship should be targeted towards a narrow subset of university researchers and not towards the population in general. They write (page 1704): "a policy measure that aims to encourage knowledge-based start-ups out of unemployment is probably doomed to fail." The reality is that although university entrepreneurship does play a role in economic development, it is a relatively small role. Perkmann and Walsh (2007, p266) highlight the modest contribution of university-industry links with regard to R&D: "In the UK, industry, commerce and public corporations account for approximately 7% of the total research income of UK HEIs (DfEL 2005). Across the EU15, the share of business-funded R&D performed in higher education and government laboratories (HERD) was 6.6% in 2002-2003."

Harrison and Leitch (2010, p1253) lament the weak links between the scientific and commercial spheres: "university spin-offs tend not to develop strong external commercially oriented relationships. This gap … is a failure by both the university and the wider business development community … commercial decisions are taken without access to all of the appropriate expertise and advice."

Vohora et al (2004) present a model of the phases of growth of university spinouts, and the problems encountered at each phase. They identify 5 phases: 1) Research (and the challenge of Opportunity Recognition); 2) Opportunity Framing (and the challenge of Entrepreneurial Commitment); 3) Pre-Organization (and the challenge of Threshold of Credibility; 4) Re-orientation (and the challenge of Threshold of Sustainability), and 2) Sustainable Returns. University spinoffs therefore face a number of obstacles as they grow, and scientific merit is not a sufficient condition for commercial success. Many scientists do not succeed in their spinoffs because of these formidable challenges.

We conclude that there is a rationale for industrial and innovation policies to focus on certain 'high-productivity or export intensive' sectors to stimulate growth. This will likely include high-tech sectors that develop or help diffuse 'key enabling technologies' such as the life-sciences or IT sectors to other sectors, traditionally viewed as 'low-tech'.

However, 'hidden innovation' means that innovative activities being undertaken in such 'low-tech' sectors also require support that is likely to be of a different nature and form (e.g. building internal capabilities of firms, assistance in adopting new process technologies or 'out-sourcing' product development) than the strong emphasis on funding support provided to R&D intensive sectors.

Similarly, it does not seem sensible for HGF policy to focus, exclusively, on high-tech sectors because HGFs are found in all sectors. Equally, the evidence does not support the notion that university spin-offs are an important source of high-growth, high-tech firms. On the contrary, other routes to diffusing knowledge generated by academic research into existing indigenous firms may be more beneficial in terms of economy wide competitiveness and growth.

1.5 Barriers to innovation and growth: a role for public policy

Barriers to growth and innovation are generally seen to be especially severe for new, small firms. When asked about the barriers they face, firms often report that they have difficulty obtaining finance, and that they would appreciate paying less tax but receiving more government support (wouldn't we all!). However, it is important to recognise that the fact that firms face financial constraints is not incompatible with the workings of a healthy economy (Coad, 2010). Not all firms deserve to obtain finance, especially subsidised finance. The reason why small firms have difficulties obtaining finance in the market is because many of them are unviable and will soon exit. The same holds for R&D projects – just because some innovation projects are cancelled for lack of funding does not mean that they should have been funded. Firms will have a number of innovation projects, and they will focus their attention on the most promising projects but neglect the least attractive projects. In this context, it is natural that marginal innovation projects will not be funded, or that marginal low-impact firms face financial constraints.

The reader should also give consideration to how the barriers mentioned in the following subsections can be meaningfully addressed by policy initiatives. For example, intense competition from rival firms is a barrier that probably cannot be removed by policymakers. Regarding other barriers, however, such as lack of qualified human resources, and a dearth of skilled employees, it is easier to imagine how they can be addressed by policy-makers.

That said, we now turn to a discussion of barriers to firm growth (Section 1.4.1) and barriers to innovation (Section 1.4.2).

1.5.1 Barriers to firm growth

What does it mean when we mention 'barriers to growth'? Where do these barriers occur? Do they prevent firms from receiving growth opportunities, or from building on them? Do they prevent firms from obtaining sales growth, or from converting sales growth into employment growth?

One class of barriers to growth might be that firms are simply not prepared for growth, as would be the case if they have inappropriate routines (e.g. non respect of health and safety or employee protection regulations) that simply cannot be scaled up. These firms cannot be scaled up without fundamentally changing their routines as a preparation for growth. These barriers to growth will limit the sales growth potential of a firm (although these firms might not grow even in the absence of such barriers).

Another class of barriers to growth might prevent sales growth from translating into employment growth. This could include lack of growth motivation or 'entrepreneurial orientation', or avoiding the responsibility of taking on new employees. It might also be that employment growth is judged to be too difficult (bureaucratic 'red tape', labour laws, lack of office space etc) even if there are sufficient sales to justify further employment growth.

The core literature[10] on barriers to firm growth has adopted a 'subjective' methodology by investigating which factors a firm reports to be important impediments to their growth. We summarise the literature in Figure 1 below and on the whole, it highlights that the key barriers are credit constraints, lack of demand, excessive bureaucracy, and lack of support from public authorities, with these problems being especially severe for small businesses. Future research would benefit by considering the 'objective' barriers (as opposed to subjectively-perceived barriers), and also considering barriers to start-up as a complement to barriers to growth.

Figure 1: Core literature on barriers to growth

Source	Data	Significant barriers
(Bagchi-Sen, 1999)	Survey of SMEs in the mature industrial region (Niagara) in the periphery of Toronto.	• Scale economies Rising import competition
(Davenport, Davies, Grimes, 1998)	Intermediary scheme of the Technology for Business Growth (TBG) programme which supports collaborative R&D projects between New Zealand industry and research institutions.	Lack of collaborative policy instruments in establishing different levels of trust
Bartlett and Bukvic (2001)	Slovenian SMEs in 2000	institutional environment (e.g. bureaucracy); external financial constraints.
(Smallbone, North, Roper, Vickers, 2003)	Extensive postal surveys conducted in southeast (SE) England, Northern Ireland (NI), and the Republic of Ireland (RoI) with a harmonised survey instrument.	• Lack of in-house knowledge • Resources in some applications External barriers
Prater, Ghosh, (2005)	Empirical data of 98 US SMEs that moved beyond exporting to setting up physical business operations in Europe.	• International communications between overseas facilities • Leveraging the outsourcing of operational functions, such as logistics Leveraging long-term alliances in Europe
Beck and Demirguc-Kunt (2006)	SMEs in 54 countries	Small firms affected most, financial barriers are important
Aghion et al (2007)	16 industrialised and emerging countries	Credit constraints
Vos et al (2007)	self-report data from US SME owners	Quality of labour; Competition (from larger or international firms)
Hughes (2008, p144)	Micro, Small and Medium enterprises in the UK, 1991 and 2004	Micro firms have become much less sensitive to costs of finance and overdrafts. Increased shortage of skilled labour over the period (for Small and Medium firms).
Coad and Tamvada (2012)	Declining Indian SMEs	Firms vary in sensitivity to certain barriers: lack of demand, shortage of working capital, non-availability of raw materials, power shortage, labor problems, marketing problems, equipment problems, and management problems.
Mason and Brown (2010, p42)	Scottish high-growth firms	No single barrier dominated. Recruitment of staff, raising finance, competitive threats from rivals competing on price, managing growth, getting customers, and obtaining planning permission.
Lee N., Cowling M. (2012)	Data: 7670 English SMEs	Significant barriers: Main barriers are national level factors: regulations, economy, and tax. Although firms in deprived areas are generally similar to firms in other areas, they have more difficulty obtaining access to finance.

[10] Some of the literature is not discussed here because it focuses on developing countries - e.g. Nigeria (McCormick et al (1997), Cote d'Ivoire (Sleuwaegen and Goedhuys 2002), and Ghana (Robson and Obeng 2008).

Bartlett and Bukvic (2001) investigate the barriers to growth reported by Slovenian SMEs, and observe that the five main barriers are the following: late payment of bills; large severance payments; cost of loans, high collateral payments; and too much bureaucracy. Paradoxically, in some cases it seems that high-growth firms are especially sensitive to growth barriers; this indicates that their high growth confronts them to particularly acute growth barriers, and suggests that without these barriers their growth might be even faster.

Smallbone et al (2003) considered the link between innovation and the use of technology (notably ICT adoption) in manufacturing plants and SMEs based in southeast (SE) England, Northern Ireland (NI), and the Republic of Ireland (RoI). In all three regions, sales growth, employment growth, and profit margins were higher for innovators than for non-innovators. However, it also appeared that although foreign-owned plants showed a higher propensity for innovation than indigenously owned plants, the latter grew faster than their foreign owned counterparts in all three regions. This suggests that a targeted strategy focused on innovative, indigenously owned firms may be particularly rewarding.

Beck et al (2005) focus on SMEs in 54 countries. Generally speaking, they observe that the smallest firms are particular constrained, and that "firms report that the financing obstacle is the most important summary obstacle to growth" (page 142). With regards to financial factors, high interest rates stand out as particularly important. With regards to the legal system, "speed of courts ... seems to be one of the important perceived obstacles" (page 146). With regards to corruption: "Of the specific corruption obstacles reported, the need to make additional payments is the highest ... The second highest rated obstacle is firms' inability to have recourse to honest officials" (page 147).

Aghion et al (2007) focus on the impact of credit constraints on the entry and post-entry growth of small firms in 16 industrialised or emerging countries. While they focus on access to credit, they also name some other barriers to entry and growth (p734): R&D & advertising undertaken by incumbents; administrative costs of entry; and labour market regulations. Interestingly enough, they observe on p743 that "successful new firms tend to expand more rapidly in the United States than in Europe" – and link this to better-developed financial markets in the US. In terms of policy implications, they write on page 771: - "a main policy indication is that many countries, including those in Continental Europe, should probably make further progress in improving their financial markets, so as to boost aggregate entry, and particularly the entry of small firms, to better select the best projects, and to promote post-entry growth of successful new firms." While we agree with their emphasis on the post-entry growth of successful new firms, we do not share their views on the virtues of boosting aggregate entry, because this could simply lead to the entry of many marginal, undersized, poor performance enterprises (aka MUPPETS; Nightingale and Coad 2012) such as solo 'lifestyler' entrepreneurs with no growth ambitions.

Vos et al (2007, Table 5) present survey evidence on the subjectively-perceived key issues for SMEs, as reported by SME owners. When asked what are the most important issues for SMEs, 15.05% report "Quality of labour", 11.60% report "Competition (from larger or international firms)", 11.09% report "Other problems", 7.33% report "Poor sales", 7.10% report "Financing and interest rates", and 7.02% report "Government regulations or red tape."

Mason and Brown (2010, p42) also present some evidence on barriers to growth, focusing in particular on high-growth (Scottish) firms. They observe that no single barrier dominated. The barriers reported by firms include recruitment of staff, raising finance, competitive threats from rivals competing on price, managing growth, getting customers, and obtaining planning permission.

Lee and Cowling (2012) observe that the main barriers to growth are reported as being regulations, economy, tax and cash flow, with a minor role for recruitment, demand, skills and location. They also observe that, although firms in deprived areas are generally similar to firms in other areas, they have more difficulty obtaining access to finance. Lee and Cowling (2012, p9) observe that the correlation between growth barriers is surprisingly low, such that reporting problems with one barrier (e.g. demand, location, cash flow) is only weakly related to reporting problems with other barriers.

1.5.2 Barriers to innovation: a literature review

Some key contributions to the literature on barriers to innovation are presented in Figure 2 below.

Figure 2 : summary of the literature on barriers to innovation

Source	Data	Findings
Baldwin and Lin (2002)	Canadian 1993 Survey of Innovation and Advanced Technology	Top barriers are cost-related, then labour-related, then organization-related.
Galia and Legros (2004)	French CIS(2) data, 1994-1996	Distinguishing between postponed and abandoned projects.
Mohnen et al (2008)	CIS (3.5) data, Netherlands	Projects not started because of lack of finance, uncertainty, and shortage of skilled labour
Mohnen and Roller (2005)	CIS (1) data from four countries: Ireland, Denmark, Germany and Italy	Barriers to innovation are interdependent, so innovation policy needs to be coherent.
Nusser, Lindner (2010)	Sector specific: Medical devices industry (Germany)	Insufficient network integration of small and medium-sized enterprises (SMEs)• Ineffective policy coordination
Dougherty (1992)	Interviews with individuals from different departments of large firms	Problems of communication and cognitive frames between individuals in large firms.
Walczuch et al (2000)	Mail survey of SMEs in the Netherlands, up to 50 employees.	Small firms are slower than large firms in adopting internet technologies
Freel (2000)	SMEs in the West Midlands (UK)	4 types of resource constraints: Finance; Management & Marketing; Skilled Labour; Information
Van Geenhuizen and Soetanto (2009)	Case study of Delft Technical University, NL	Barriers especially severe for young businesses
D'Este et al (2012)	UK CIS (4) data	Distinguishing between revealed and deterring barriers.

A pioneering investigation of barriers to innovation facing new firms can be found in Baldwin and Lin (2002). Their paper (in particular, Tables 3, 4, 6, and 7) is a trove of findings on which firms are more susceptible to barriers to innovation. To begin with, they investigate the benefits and effects of advanced technology adoption, and list a number of factors, the most important of which are: improvements in productivity; increase in skill requirements; reduction in labour requirements; and improvement in product quality.

They observe that while barriers may exist, nonetheless firms are able to struggle against these barriers and overcome them: "They may be barriers; but they are barriers that do not stop innovation and the adoption of new technologies. They are obstacles that are overcome as technology is introduced into the plant" (page 17). Subsequent work has distinguished between barriers in postponed projects and barriers to abandoned projects (Galia and Legros 2004). Galia and Legros observe that the factors leading firms to abandon projects are essentially economic barriers rather than technological or organisational barriers. Factors leading firms to postpone projects are linked to economic risk, lack of skilled personnel, innovation costs, lack of customer responsiveness, lack of information on technologies and organizational rigidities.

Baldwin and Lin (2002) write that the top three barriers are, first, cost-related, then labour-related, then organisation-related. Less important are information-related and institution-related factors. This is reminiscent of findings in D'Este et al (2012, Table 1), who find that cost-related barriers are the most important, followed by market-related barriers, then regulation-related factors and finally knowledge factors.

Mohnen et al (2008) investigate a number of types of barriers to innovation, listed here in terms of importance (most important first): Economic uncertainty; Market uncertainty; Costs too high; and Financial constraints. These factors have different impacts at different stages of innovation projects (Abandoned; Prematurely stopped; Seriously slowed down; Did not start, see their Table 2). They observe that: "Financial constraints, cost considerations and economic uncertainty, organizational rigidities and regulations are the reasons most often mentioned for not starting a project." (page 204). In contrast: "Shortage of personnel, shortage of knowledge, market uncertainty and other factors most frequently lead to seriously slowing down a project" (page 205).

Financial constraints appear prominently among the barriers facing firms, although it is not always the most important constraint (Mohnen et al, 2008). This relatively important role for financial constraints occurs despite the financial incentives that are already in place to help firms overcome these financial barriers. "Financial constraints continue to hamper innovative activity despite the fact that the tax treatment of R&D is favourable to innovations" (page 212). They also observe that: "Hampering factors such as shortage of qualified human resources have received less attention in the innovation literature than financial constraints" (page 212). Other barriers to innovation include uncertainty about the gains from the technology (Walczuch et al 2000) or problems of cognitive framing and communication within large organizations (Dougherty, 1992). Barriers noted by Nusser & Lindner (2010) include insufficient network integration of SMEs and ineffective policy coordination.

The existence of complementarities between different facets of innovation policy was investigated by Galia and Legros (2004) and Mohnen and Roller (2005); the latter focus on four types of barrier to innovation: lack of finance, lack of skilled personnel, lack of opportunities for cooperation, and legislation, norms regulation, standards and taxation. Interestingly they observe that the factors that interact to have an influence on the *probability* of innovation are not the same as those that interact to influence the *intensity* of innovation. Instead, probability of innovation, on the one hand, and intensity of innovation, on the other, are subject to different constraints. The complementarities between barriers observed by Galia and Legros (2004) exist between costs of innovation and sources of finance; as well as complementarity between lack of information on markets, institutional environment, and customer responsiveness. Complementarity between barriers to innovation suggests that innovation policies should be multifaceted and coherent.

Freel (2000) investigates the barriers to innovation in a sample of SMEs in the West Midlands (UK). The 5 top-ranking factors allowing an increase in Innovative activity (most important listed first) are: improved in-house technical skills; improved in-house managerial skills; increased in-house technical personnel; improved in-house marketing personnel; access to external marketing expertise (Freel, 2000, Table 5).

Barriers may indeed have different effects at different stages of the innovation process. Frontline (2012) analyse Scottish technology start-ups and observe in particular that: "skills barriers peaked during product development and production/marketing stages" (p19). Frontline (2012) also report that, among the sources of assistance offered by Scottish Enterprise, “Advice remains the highest rated service” (p21).

To summarise, the evidence suggests that firms perceive that economic barriers and financial constraints exert strong effects on hampering innovation. However, we also acknowledge that there are already many policies in place to alleviate these financial pressures. Furthermore, we would expect some innovation projects to be discarded for reasons of financial constraints even if financial markets were perfect – because some innovation projects are just not commercially viable. However, one barrier to innovation of interest to policy-makers is the lack of skilled employees – this problem could be addressed by seeking to improve the skills of the workforce (not just at the university level, where Scotland already performs very well, but at the level of the broader workforce population), perhaps targeting certain core areas such as IT (as emphasised by Freeman and Soete in 1994, although their message is still very relevant today as illustrated by the fourth commitment of the EU’s Innovation Union policy agenda on e-skills).[11]

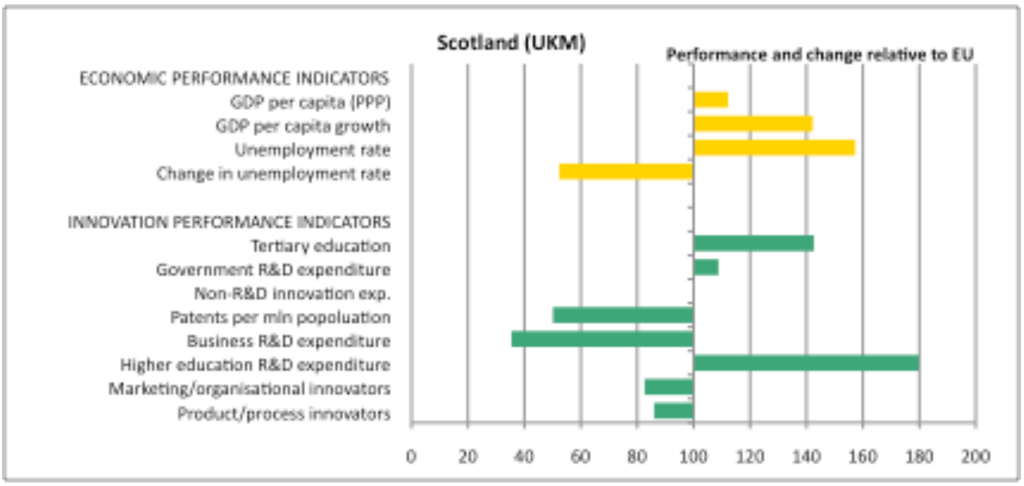
[11] http://i3s.ec.europa.eu/commitment/4.html

2. Scotland: technology development and economic growth: a review of the evidence

We were asked *to review what constitutes the main sources of technology and innovation in Scotland and how this compares with other (regional) economies*. In order to do so, this chapter summarises briefly (section 2.1) the available literature on the Scottish innovation system and then conducts an analysis of the relationship between business R&D and innovation activity and growth and employment in the Scottish economy (section 2.2). In addition to comparing Scotland with the rest of the UK and the EU average, the Scottish case is put in context of the neighbouring Nordic economies and Ireland. Wherever possible, a distinction is made between the technological intensity of business sectors (high-tech, medium-high tech, etc.).

As illustrated in Figure 3 Scotland's innovation performance is highly dichotomous with a relatively strong higher education and public research performance versus business innovation and entrepreneurial activity that lags behind the EU27 average. Turnbull and Richmond (2011) investigate the innovative performance of Scottish firms and observe in general that Scotland's BERD is rather low (p62): "Scottish Business Enterprise R&D (BERD) expenditure was 0.56% of Scottish GDP in 2009, lower than the rate for the UK as a whole (1.11%)." Furthermore, they observe that (p68): "Scotland's business innovation performance lags the UK as a whole for most innovation indicators", and that the lagging performance of Scottish firms is primarily due to SMEs – large firms seem to be relatively successful in terms of the innovation indicators investigated.

Figure 3: Scotland's economic and innovation performance relative to other EU27 regions



Source: Regional Innovation Monitor, 2011, http://www.rim-europa.eu/ - Data used is from 2011 or latest available year depending on the indicator.

A number of recent studies categorise European regions by their innovation 'profile', to facilitate benchmarking of performance and policy options of regions facing a similar set of challenges or opportunities. Hollanders and Wintjes (2010) classify Scotland, along with most other UK regions, as a 'knowledge absorbing region'. Ajmone Marsan & Maguire (2011) developed a typology of regional innovation systems for the OECD and classified Scotland in a group of service and natural resource based economies along with a large chunk of the Nordic regions[12]. Technopolis Group (2011)

[12] This cluster contains 28 regions, accounting for 5% of the sample population and 5.6% of the sample GDP. They may generally be considered second-tier hubs in their countries. These regions are located in Northern Europe (four regions in Denmark, three in the Netherlands, one in Finland, seven in Norway, four in Sweden, one UK), Asia (two Korean regions), Canada (4 regions) and Central or Eastern Europe (Luxembourg and Bratislava region). Patenting and R&D intensity are medium to high and the average share of employment in knowledge-intensive services is among the highest of all clusters. The unemployment rate is the lowest on average among the clusters.

characterise Scotland as a 'public knowledge region'[13] due notably to the dominant role of higher education and government research sectors in R&D expenditure (as a % of GDP). This group has an average share of tertiary educated citizens as high as that of the 'high-tech business innovating regions' and the group, as a whole, does not have a major weakness in any of the eight core indicators used.

These typologies while pointing to certain characteristics of the Scottish innovation performance are based on a relatively traditional set of 'input' and 'output' indicators for 'R&D' driven technological change. How the 'innovation performance' of the region is then linked to economic development is less often explored. However, Hollanders & Wintjes (2010) argue that 'High-tech regions'[14], have experienced lower growth than regions that have increased their capacity in knowledge absorption. They argue that a region's capability to absorb external knowledge depends on the level of skills, equipment and professional networks operating in the region as well as on the availability of knowledge intensive services. Knowledge spillovers from openness to technological opportunities, the incidence of outsourcing and the degree of interdependence among competitors further reinforce the absorption capacity.

2.1 How does Scotland's academic research contribute to economic development?

Given Scotland's remarkably strong higher education R&D performance, it could be assumed, and indeed this is an explicit policy assumption over the last decade, that economic growth and business development could be sourced from the knowledge generated in the higher education sector. Scotland as a whole spends slightly less per year (see Figure 11) than the UK (although the North-East of Scotland outperforms all comparators) but the balance between R&D performed by the higher education sector versus the business sector is significantly different from the UK and EU27 averages.

In terms of scientific output, from 2000-2011, 83% of Scottish scientific publications were concentrated in only five fields (see Figure 13 in annex). Indeed, the two life science fields (medicine and biomedicine, genetics and molecular biology) dominate Scottish scientific output. Output per se is not a clear indication of scientific impact which is measured by two criteria: publication rates in high-impact journals and citation rates. Scotland, due to scale, is not among the top 20 countries in the world in terms of total publications in any field, but does perform well in terms of citation impact in a number of fields and notably in space-science, materials, pharmacology & toxicology and physics (see Figure 14). Moreover, penny for penny of investment, Scotland appears to outperform similarly sized neighbouring countries in terms of scientific impact[15].

The question remains whether the areas in which Scottish scientific performance is above average contribute to the priorities of the Scottish Government's economic strategy. Indeed, for scientific results to have an economic or societal impact they need to be developed into exploitable technologies or, perhaps more importantly, foster the skills base via education and other forms of knowledge transfer. As noted above, the attention of policy makers is often strongly focused on university spin-offs or patenting as indicators of a return from investment in academic research. However, the Scottish Government has adopted a broader measure as a national performance indicator, namely: "Improve Knowledge Exchange from university research"[16].

[13] The 21 regions in this group are scattered across Europe, including many capital regions such as Madrid, Rome, London, Berlin, Prague, and Bucharest, but also regions in Eastern Germany, Scotland and Southern France.

[14] High-tech regions including 17 R&D-intensive regions in Germany, Finland, Sweden and the Netherlands. These regions perform above average on absorption capability, diffusion capacity and accessibility to knowledge. Their level of economic performance is above average.

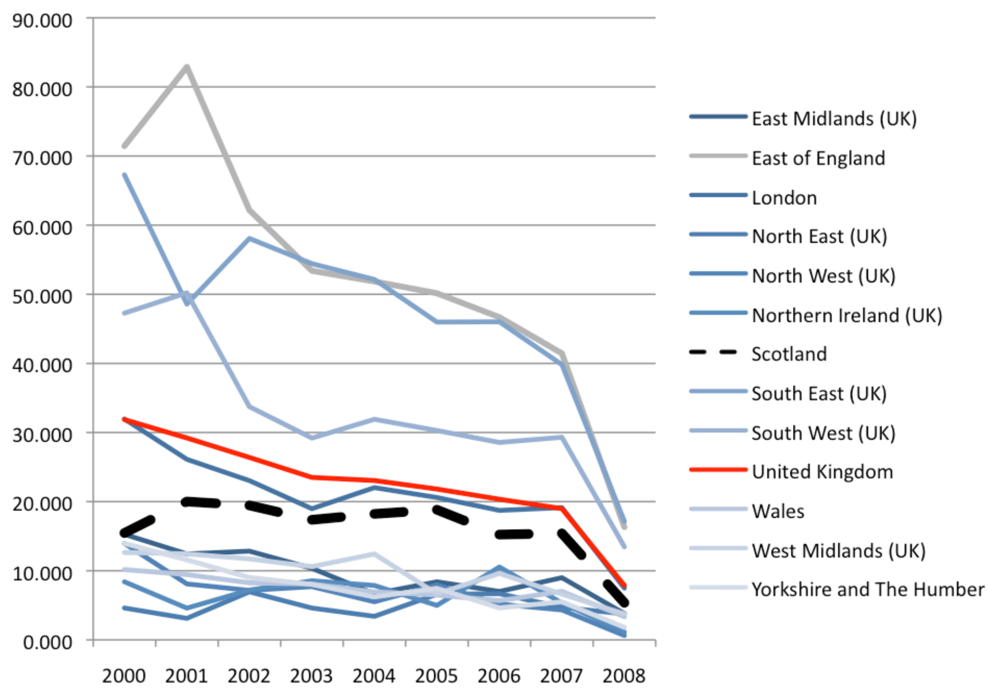
[15] For example, over the period 2003-2007, Scotland and Finland spent roughly an equivalent amount (around €1.05bn) per annum on higher education R&D. Yet, Scotland outperformed Finland in most fields, apart from geosciences, education and social sciences where Finland has a lead and ecology/environment and clinical medicine where performance is similar.

[16] The indicator is measured by using the Scottish Funding Council's (SFC) Knowledge Transfer Metrics Return. This dataset records the income received by all SFC-funded Scottish Higher Education Institutions (HEIs) from knowledge exchange activities, designed as a means of allocating a grant for knowledge exchange. The Indicator captures the Scottish Higher Education (HE) sector's income from a variety of knowledge exchange activities ranging from the commercialisation of new research to delivery of professional training, consultancy and services. In this respect, the indicator is a proxy measure of the quantity, but not the quality, of knowledge exchange activities undertaken by Scottish universities.

More generally, patent statistics are often used as a proxy for technological specialisation of an economy and 'innovation output' from both public and business R&D investments. Comparing trends in high-tech patents in Scotland and the UK regions, Figure 4 suggests that there is deterioration in high tech patenting activity across all regions over the period 2000-2008. Scotland performs similarly to the UK average with an observable stagnation in patenting rates despite the very high impact factors of publications and the Scottish Government's efforts to invest in research commercialisation.

Even looking at disaggregated data on the patents per high-tech sector, neither the UK nor Scotland record noticeable growth in any of the high-tech fields. Moreover, the trends for Scotland appear to be more volatile than the overall UK trends. From the available data, it is impossible to disaggregate further to investigate the drivers behind the observed patterns or to draw inferences on the number and size of organisations (universities, high-tech companies) behind these figures. However, Frietsch et al (20) found that only about 40% of UK patent applications at the European Patent Office (EPO) stem from large multinational enterprises, suggesting that the UK industrial structure is is dominated to a larger extent by smaller firms than the main competitors (Japan, Germany, France and the US). This would confirm earlier research (covering the period 1986-2000) that found that smaller firms were disproportionately active in acquiring IP assets via the UK Patent Office and even via the EPO there was no strong evidence that size matters for patenting propensity. However, there is a need for further research into intellectual property strategies (considering not only patents but trademarks, industrial design copyrights, etc.) of Scottish based firms in order to understand the significance of this overall negative trend for the high-tech sectors.

Figure 4: High-tech patenting trends by UK region



Source: Eurostat, calculations authors

Considering the spin-off route, Harrison and Leitch (2010, page 1246) observe that Scotland has an IP income above average, a relatively strong performance in IP income generation, but a low performance in revenue from university spin-off sales. The latter result is all the more surprising since data (Appendix E) shows that the spin-off performance of Scottish Universities is remarkably strong. The University of Edinburgh is top of the list of a 150 UK universities (by a large margin), and two other Scottish institutions appear in the top 10 (University of Strathclyde, 6th, and University of Glasgow, 10th). However, very few spin-outs go on to achieve high growth. a 2008 study (Targeting Innovation, 2008) found that out of 200 spin-outs from Scottish universities created since 1997: 30% were no longer trading, 55% employed less than 10 people, while just 15% employed more than 50 people. The study underlined that only six spin-outs had developed to become substantial businesses (200-400 employees at the time of the study). This finding was reinforced by Mason and Brown (2012) who found that very few technology based firms in Scotland emanate from a University background. So the challenge seems more related to ambition or capabilities to grow than creation of new spin-outs.

In addition to the role of universities in generating spin-off companies, universities also play an important role as a source of knowledge that can be applied by firms for commercial purposes. On this issue, Harris et al (2012) investigate the links between higher education institutions (HEIs) and firms, and the impacts of these links on establishment-level productivity in UK regions. Overall they find that there is a positive impact of HEI-firm links on productivity, in line with expectations. With respect to Scotland, they find that Scottish firms that source knowledge from HEIs do worse than their counterparts in other UK regions, but that foreign-owned subsidiaries in Scotland seem to do much better. There seems to be a gap between indigenous firms with weak absorptive capacity, on the one hand, and foreign-owned firms with stronger absorptive capacity, on the other. Scotland therefore seems to suffer from weak links between HEIs and firms in terms of knowledge transfer. We suggest that policy-makers could focus on the reasons why indigenous Scottish firms have a low absorptive capacity and then attempt to remedy this situation.

Indeed, despite a swathe of funding for knowledge transfer actions at individual universities, there still appear to be significant difficulties in maximising the spillovers from business-university interactions. The launch of the Interface structure in 2005 and the associated innovation vouchers are one instrument aimed at encouraging firms that are not the 'usual partners' of universities to begin co-operating. Although Interface and the voucher scheme has achieved good results, the question remains if a brokerage type service is enough to overcome the weak absorption capacities of the broader SME base.

The Scottish food and drink sector is one example of a 'low-tech' sector (in terms of BERD intensity) that performs well in terms of export growth and GVA trends, but which is characterised by a dichotomy between a limited number of large (often multinational) firms and a broader base of smaller (often still family owned) firms with no or limited internal capabilities. Recently, two main initiatives have been taken to structure the access of food and drink firms to knowledge from both the academic sector (Interface Scotland has been tasked with a specific mission to support food and drink innovation) but also advice and support for product and process development even for those firms lacking in-house R&D capacities. The Food & Health Innovation Service (http://www.foodhealthinnovation.com/) that has been contracted out to a private RTO, Campden BRI (http://www.campden.co.uk/) which counts about 200 of the 250 Scottish Enterprise account managed food and drink companies amongst its membership. While it is too early to appraise whether this will be successful in raisin innovation activity in the sector, it is an approach that recognises that the main source of innovation for most SMEs is from industry specialists, customers, suppliers, etc.

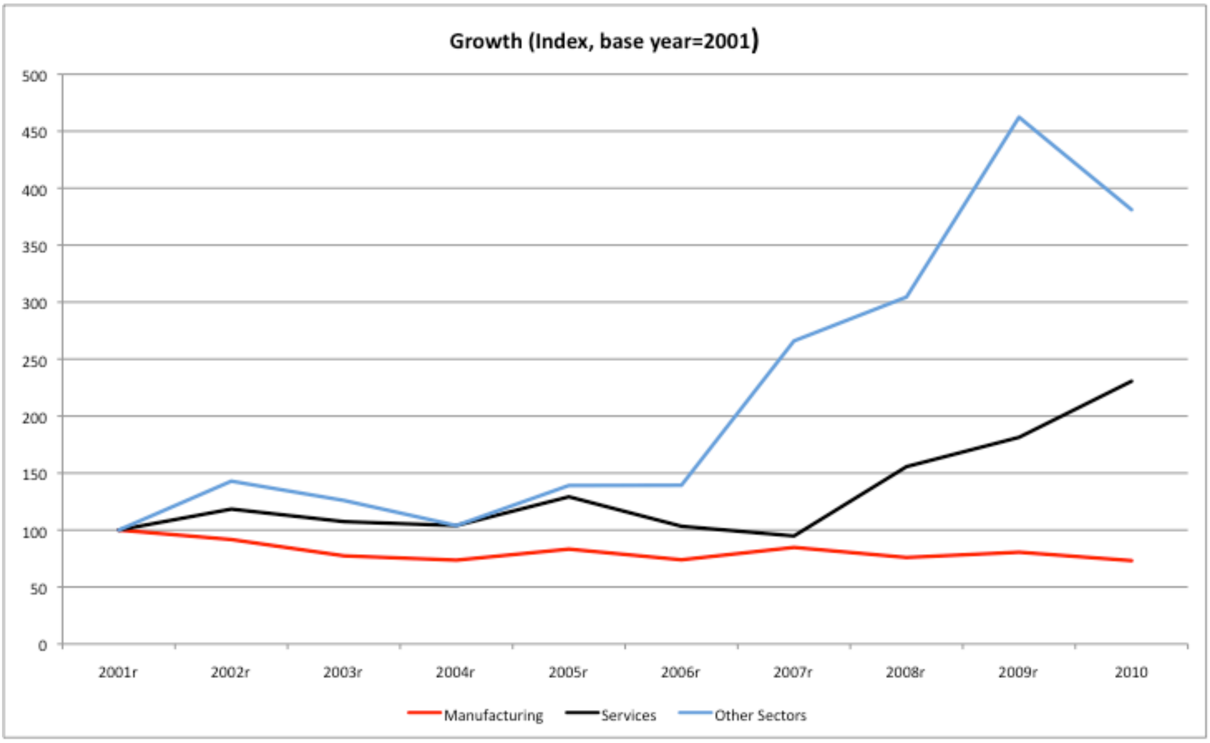
Indeed, the problems in translating excellent university research into economic performance may be more related to the schism between the UK's high share of highly-skilled workers and the modest share of intermediate skilled workers (Beath, 2002). Roper et al (2006) observe on page 30 that "Scotland is below average for ... public investments in education..." Scotland seems to invest a lot in university-level education, but much less in schools. It could be that this apparent underinvestment in the schooling of the broader population is one factor that explains the low absorptive capacity that seems to affect Scottish firms (i.e. where 'absorptive capacity' is related to the 'popularisation' of innovations and the wider application of new technologies). Riddell et al (2009) found that lifelong learning practices in Scottish SMEs tend to entrench existing inequalities by differential access to and participation in workplace learning where those with existing high levels of qualification have far greater opportunities. Traditional manufacturing firms had a more restrictive approach to learning, encouraging employees to undertake courses which would give them the skills to do their jobs more effectively, but placing less focus on the skills required for their wider growth and development.

2.2 Does business R&D investment drive growth in Scotland?

Even if Scotland is investing relatively less in business expenditure on R&D (BERD) than comparable European regions and neighbouring countries, it is relevant to ask if there is a link between this business R&D activity and economic growth. In common with most countries, the highest share of

BERD in absolute terms in Scotland in is the manufacturing sector. However, in terms of growth (see Figure 5) the fastest growth in R&D expenditure is recorded in the "other" sectors group[17], notably driven by the **extractive industries** (the oil and gas sector). Although manufacturing is important in absolute terms, the trend line is flat since 2001, although as discussed below this is not exceptional compared to other Western European countries. However, no noticeable growth is observed in any sub-division of the manufacturing sector (other machinery; transport equipment and aerospace; electrical machinery; mechanical engineering; chemicals).

Figure 5: growth index of R&D expenditure performed by businesses in Scotland



Source: data Scottish Government, calculations authors

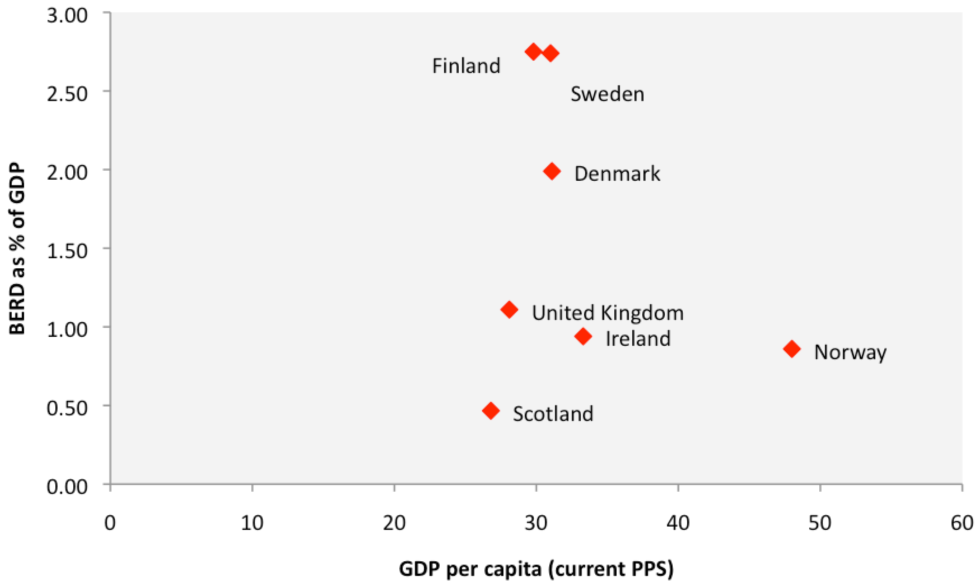
Evidence on the link between BERD and economic growth can be found in comparing Scotland to its northern European counterparts: Denmark, Finland, Ireland, Norway, Sweden and the UK (including Scotland). Figure 6 illustrates that Scotland has a lower business R&D intensity compared to three Nordic countries (Denmark, Finland, Sweden) and to a lesser extent Ireland and Norway and the UK.

As there is no indication of either positive or negative correlation[18], there are at least two interpretations possible: Scottish businesses are under-investing or others are over-investing. Another issue is that this data does not take account of the role of non-technological (non-R&D) based innovation activities and their contribution to overall innovation performance, productivity, etc. as has been mentioned above for the Norwegian case.

[17]:The "Others" category includes: Agriculture, hunting & forestry, Fishing; Extractive industries; Electricity, gas & water supply; Construction.

[18] It would be necessary to expanding the sample of countries to further explore the correlation issue. Regardless, it should be stressed that correlation does not mean causation, which means that more sophisticated approaches to establishing the relationship between BERD and economic growth, are needed. Such approaches could range from regression analysis to econometric techniques targeted for causal/counterfactual analysis (such as matching, instrumental variables, and regression discontinuity design, as well as complex causation/multiple conjunctural causation). Especially in the latter case applications using micro level data (firm) instead of aggregated macro level data (country) are preferred, although the availability of such extended datasets is an issue.

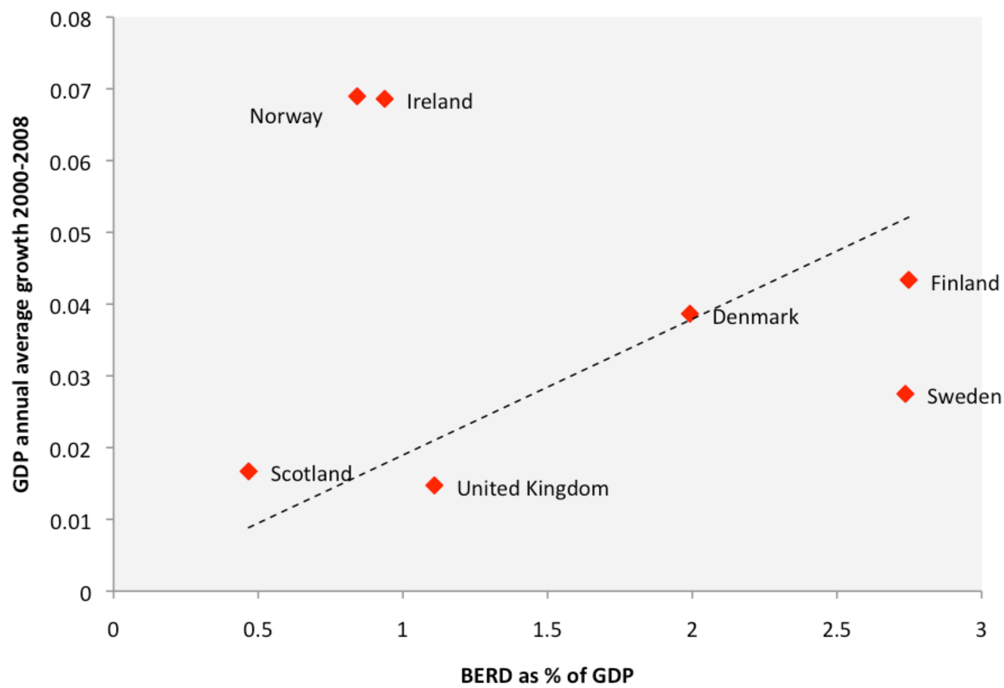
Figure 6: Business R&D and GDP: Scotland & selected northern European countries (2008)



Source: data EUROSTAT, calculations authors

In order to assess the extent to which economic growth may be attributable to BERD Figure 7 plots annual average GDP growth against BERD as a percentage of GDP in 2008. Each point corresponds to the countries reflecting the average annual volume percentage change of GDP (2000-2008) and BERD (percent of GDP in 2008). It can be observed that the northern European countries are highly diverse. Scotland, like the whole of the UK, belongs neither to the group of high average annual growth/low BERD (Norway and Ireland) nor the group of high-intensity BERD investors.

Figure 7: Business R&D and Economic Growth: Scotland among selected countries



Source: EUROSTAT, calculations authors

The evidence so far positions Scotland at the tail end of selected northern European comparator countries both in terms of growth and business R&D performance. The results obtained however are not robust enough to allow us to draw policy conclusions. The evidence does suggest that high growth rates can be achieved without correspondingly high rates of BERD. This is not the same as saying that high growth can be achieved without innovation or technology diffusion. For instance, Scotland could potentially follow a similar model to that of Norway, where a low R&D intensity is explained more by the economic structure but where technology intensity in the economy (even in so called 'low-tech' sectors) is extremely high. Hauknes & Knell (2009) show that the medium-high and medium-low tech industries, identified as specialised-supplier and scale-intensive industries, including knowledge-intensive business services (KIBS), are essential for the production, diffusion and use of technology, and hence for economic growth.

In understanding business R&D intensity it is important to take into account differences in the industrial structure and business demographics (weight of different size classes) of a country or region, since variations in sectoral business cycles (as well as size of companies) can be important determinants. In particular, according to the OECD (2011), industrial structure helps explain a country's differences and difficulties in increasing R&D intensity. Such an approach is of particular interest when comparing across countries in order to understand the extent to which structural differences can account for observed differences in overall business R&D[19].

The OECD findings suggest that after adjusting business R&D for economic structure a number of countries (including Finland) that are relatively specialised in high and medium-high technology industries fall below the OECD average. The contrary is observed for countries like the Netherlands and France which have adjusted BERD intensity higher than the OECD average. For countries that do not experience any significant change in adjusted BERD intensity, the implication is that business R&D is lower than average regardless of sectoral specialisation.

Due to difficulties in accessing disaggregated data and the scope of the current study, it was not possible to replicate the calculation for Scotland and hence compare with the OECD results for other EU countries. However, a preliminary calculation would suggest that adjusting for industrial structure would increase Scotland's BERD intensity but still leave it well below the OECD average (as is the case for the UK as a whole). Further analysis would, however, be needed before any firm conclusions on the importance of the sectoral structure of the Scottish economy as an explanatory factor for low BERD intensity can be drawn.

Nevertheless, innovation survey results for Scotland tend to confirm that industrial structure is likely to one part of the explanation behind Scotland's perceived 'lag' in innovation-driven growth. Turnbull & Richmond (2011 a & b) noted that small and medium sized firms in Scotland underperform relative to the UK while large firms do better, and, for Scotland (and for the UK as a whole), innovation activity increases with firm size. However, they argued that rather than class-size '**industry structure** is the main influence on differences between the UK and Scotland in overall **product** innovation performance'. Moreover, based on a sectoral analysis of the CIS 2009 data, they argued that the lower proportion of innovation active firms in Scotland can be partly explained by the sectoral composition of the economy.

> *Although in most sectors covered by the survey the proportion of innovation active firms in Scotland is around the UK average, there are two sectors with large gaps in performance compared to the UK. Traditional manufacturing performs above the UK average while wholesale & retail perform below the UK average. As Scotland has a smaller proportion of traditional manufacturing firms in the business base than the UK and a higher proportion of retail, the relative size and performance of these sectors will negatively affect Scotland's overall innovation performance.*

A second key element of the findings of the CIS 2009 for Scotland is that while Scottish BERD intensity is well below the UK average, Scottish firms innovation expenditure is markedly (3268 versus

[19] The OECD constructed an indicator that shows what a country's total R&D intensity would be if it had the same industrial structure as the average for OECD countries. The so-called 'structure-adjusted indicator of R&D intensity' is a weighted average of the R&D intensities of a country's industrial sectors, using the OECD industrial structure (sector value added shares in 2007) as weights. This is then compared to the R&D intensities weighted by a country's actual shares. Replicating such an analysis for Scotland would therefore require access to disaggregated data per sector for value added and BERD (using the standard industrial classification).

3018) above the UK average. Turnbull & Richmond (2011a) concluded that although a slightly lower proportion of Scottish companies invested in innovation they tended to invest more than the UK average. However, the pattern of investment is markedly different as firms in Scotland invested a much higher proportion of their total innovation expenditure in bought-in technology (38% vs 24%) and training (21% vs 3%) than the UK overall, but much less in marketing (one third) and external R&D (3% vs 19%). Turnbull & Richmond (2011a) again argue that these differences are at least partly due to the sectoral composition of the Scottish versus UK economies.

Internal R&D is considered to be a key condition for both new product development and knowledge absorption. The Scottish share of internal R&D (at 30% of total innovation expenditure) is only three-quarters of the UK average yet at the same time, the data suggests that Scottish firms (in all size classes) generated a higher percentage of turnover from new to market products than the UK average. Scottish firms innovation activity, on average, appears therefore to be more driven by process related innovation.

Hence, the available evidence suggests that Scottish firms innovation performance is more widespread and intense than business R&D statistics would suggest, prima facie. Hence, innovation, notably through embodied technology and training, may be contributing to sustaining a gradual closing of the Scottish productivity performance compared to the top quartile of OECD countries from 2002 to 2009 (Turnbull & Richmond 2011a). This would be consistent with research suggesting that intangible investments are becoming an increasingly important driver of multi-factor productivity (OECD, 2011, BIS, 2011).

Given the available level of disaggregated data, it is impossible to distinguish the role of specific high-tech sectors within the CIS findings. However, (Turnbull & Richmond 2001a) note that 'comparing the pattern of traditional R&D expenditure by sector with innovation expenditure highlights that innovation investment is more widespread across sectors than R&D activity alone and includes sectors not traditionally associated with R&D such as wholesale & retail and hotels & restaurants'.

However, while innovation may be more widespread than BERD data suggests lower levels of internal R&D would imply that Scottish firms absorptive capacity[20] is lower than it should be and that the low levels of BERD still remain a cause for concern. Both Roper (2006) and Harris et al (2011) have identified absorptive capacity as a weakness of Scottish businesses suggesting that there is a need to further expand the base of indigenous SMEs undertaking internal R&D.

Combining the evidence from that shows that BERD growth has been driven by 'lower-tech' manufacturing and extractive industries, with the evidence on innovation expenditure and activity at sectoral level, we conclude that Scotland has significant 'hidden innovation' in a wider range of sectors than generally assumed. However, that this innovation is largely done through technology adoption rather than more radical product development. Hence, although 'hidden innovation' plays a useful role in modern economies, it is no substitute for 'visible innovation' which arguably makes more of an impact in terms of productivity growth and economic growth.

More fundamentally, there is little evidence that 'high-tech' sectors or 'hi-tech-high growth' firms are the driving forces in the Scottish innovation system. This is not a weakness per se but rather should be viewed as an opportunity to realign innovation policies from an 'over-emphasis' on research commercialisation towards encouraging more intensive in-house technological and non-technological innovation in indigenously owned small to medium sized enterprises.

[20] Defined as a firm's ability to recognise the value of new information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990) Absorptive capacity depends on prior related knowledge and the diversity of background. Hence, an internal R&D team will increase the absorptive capacity of a company. Absorptive capacity is one reason for companies to invest in R&D instead of simply purchasing the results post factum (e.g. patents). Absorptive capacity is a cumulative process, meaning that it is easier for a firm to invest on a constant basis in its absorptive capacity than investing punctually.

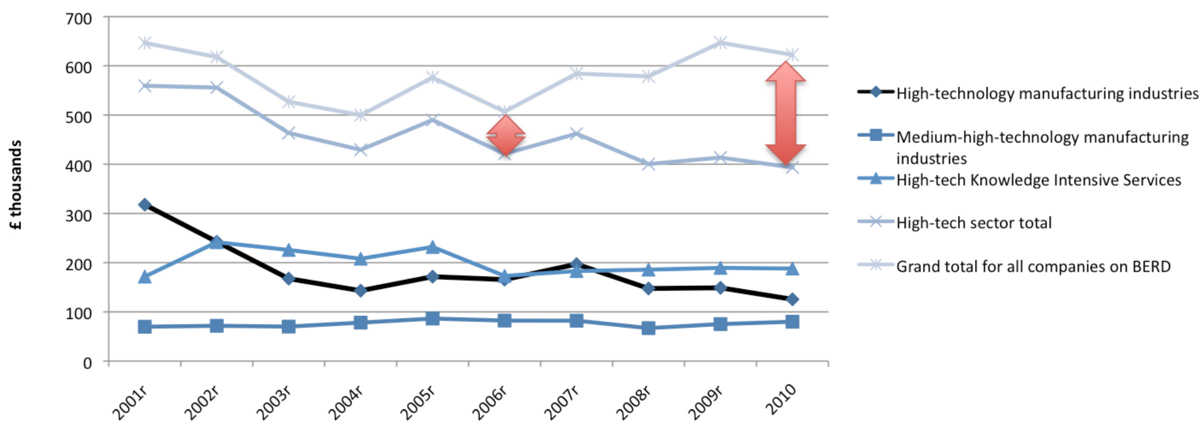
2.2.1 The contribution of high-tech sectors to Scottish growth

The same question-marks arise for the high-tech sector. We are therefore interested in the extent to which BERD in the high tech sector impacts economic growth. In this case given the availability of the Scottish Annual Business Survey (ABS) and BERD data provided by the Scottish government (see Annex I), it is possible to discuss the cases of GVA and employment look at the trends for the different divisions of the high-tech sector (High and Medium High tech manufacturing; Knowledge Intensive Services) and the total the entire high-tech sector compared to the grand total for BERD (

Figure 8).

In absolute terms the high tech sector invests significantly in R&D. At the same time, as illustrated by the red arrows, the gap between total BERD and High-Tech BERD has widened. However, this conclusion should be nuanced since a statistical break in the time series as of 2009/2010 might be partly responsible for the observed pattern (see Appendix B). Nevertheless, the time series data suggests that R&D expenditure in the high-tech sub-sectors has remained stagnant or declined. At the same time, there has been an increase in business R&D in the "other sectors".

Figure 8: R&D expenditure performed within high-tech businesses in Scotland



Source: data Scottish Government, calculations authors

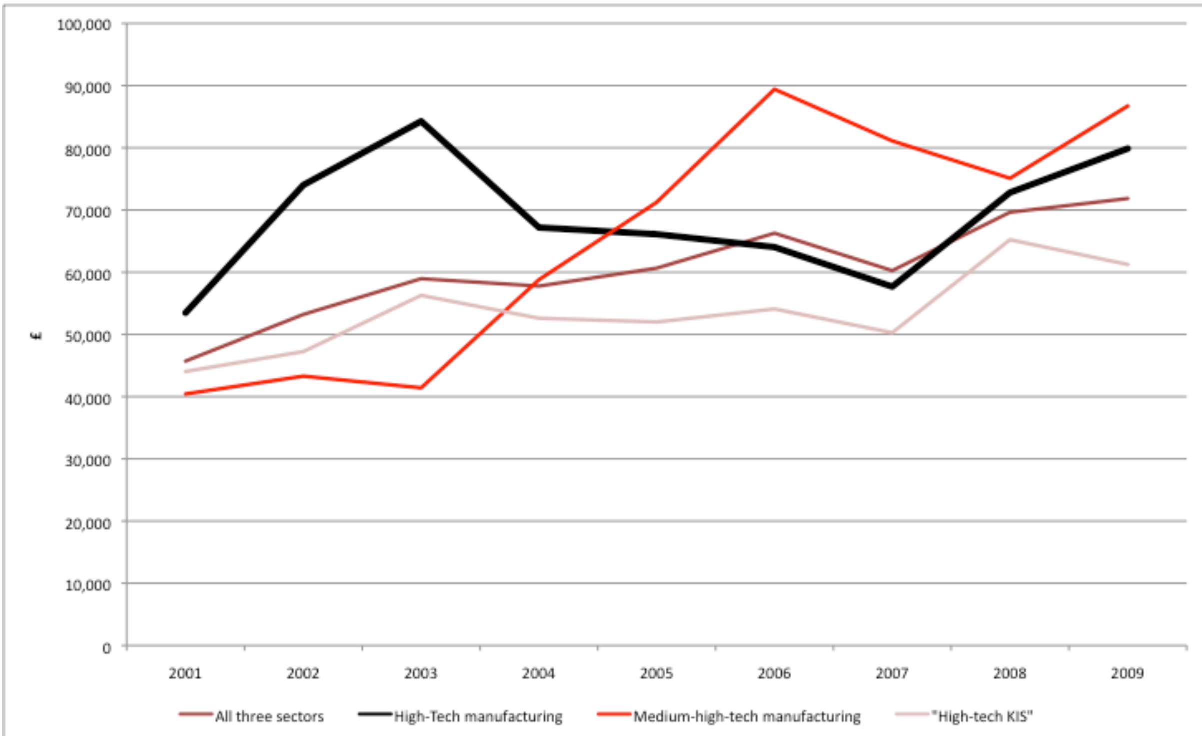
GVA is of particular interest to policy makers when measuring the impact of research and innovation policy measures. The initial observations drawn by plotting Scottish GVA in the high-tech sector (see Figure 9) are that there is an overall upward growth trend of GVA in the Scottish high-tech sectors:

- This growth was driven by medium high-tech manufacturing the period 2003-2006, whilst there has been little or no growth in the other two high-tech sectors;
- since 2007, GVA growth in the high-tech manufacturing sector has picked up whilst growth in the high-tech KIS sector has fallen off after an upward jump from 2007-8.

A correlation analysis was performed to assess the relation between GVA and the high tech sector per division. The results show a strong positive correlation for 'all three sectors' and high-tech and a slightly negative correlation for medium high-tech[21].

[21] These results suggest there is a need to look deeper into this relation by using more sophisticated econometric analysis, like for example multivariate regression analysis on the level of firm (which, however, available data does not allow).

Figure 9: GVA in the high-tech sectors



Source: data Scottish Government, calculations by authors

Notes: Gross value added is a measure of the income generated by businesses after the subtraction of input costs, but before costs such as wages and capital investment are paid prior to arriving at a figure for profit.

An equivalent analysis for employment was performed for the trends in employment per high-tech division (see Figure 10). An overall decline in employment in the high-tech sector in Scotland since 2001 is observed. There is a marked decline for high-tech manufacturing and medium-high-tech manufacturing which has not been offset by an increase of employment in knowledge intensive services (which has basically flat-lined since 2001).

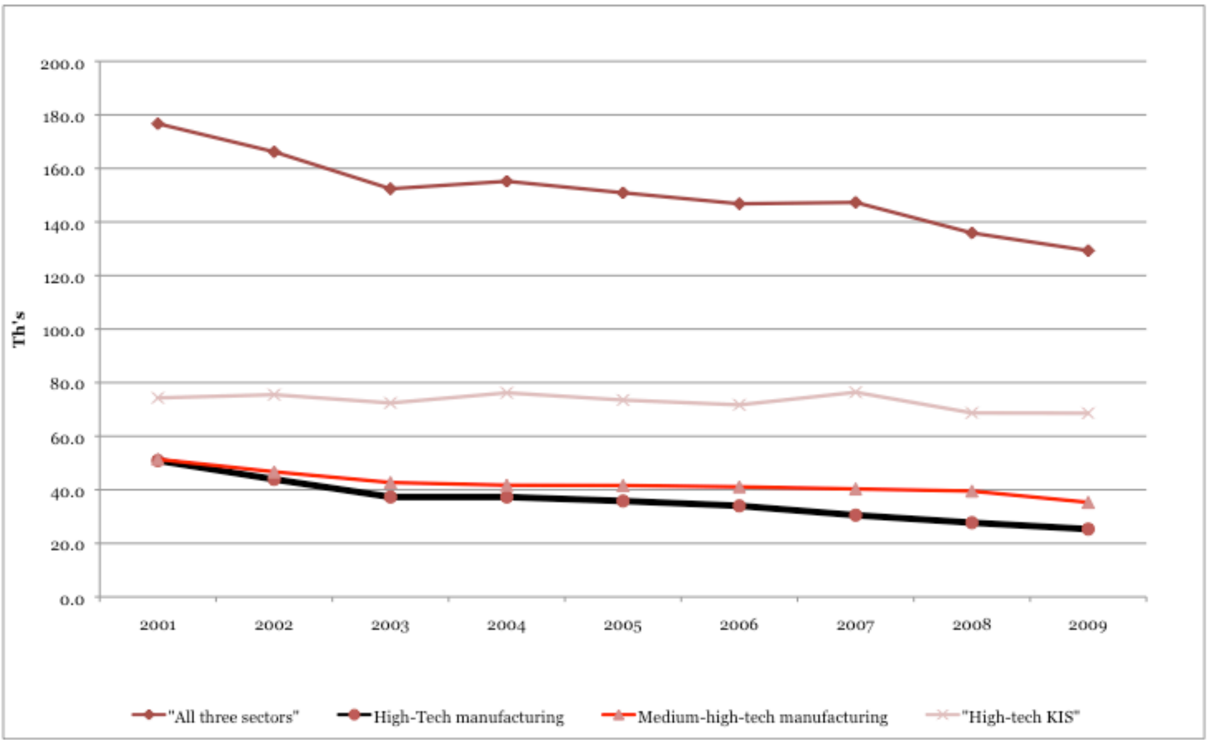
An analysis of the relationship between employment and the high-tech sector per division produced a mix of both positive and negative coefficients that did not allow drawing firm conclusions. At best, an interpretation would be that R&D investment is having a positive effect on GVA and productivity in the high-tech sectors, but that this growth is not 'employment rich'.

Moreover, the decline in medium-high tech and high-tech manufacturing employment is a consequence of structural change (driven by largely global trends) rather than a direct replacement of workers by technology (in a luddite sense). Indeed, overall manufacturing employment in Scotland fell from 284 to 190 thousand in the period from December 2001 to December 2011[22], while across the EU27, employment in high-tech manufacturing declined by 4.5% between 2008-10[23]. Of course, this has an effect on the potential BERD intensity of the economy. The European Commission (EC, 2011) in the Innovation Union Competitiveness Report noted that overall, most European economies, with the exception of Germany, Austria, Hungary and the Czech Republic, have experienced an evolution towards a lower weight of research-intensive sectors in the economy, mainly due to the long-term shift from manufacturing to services. Indeed, the UK, as a whole experienced the most severe shift.

[22] Source: http://www.ons.gov.uk Workforce jobs by region and industry (updated March 2012), data consulted online August 2012

[23] See: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/High-tech_statistics

Figure 10: Employment in the high-tech sectors in Scotland (2001-2009)



Source: data Scottish Government, calculations by authors

The results of the analysis for Scotland appear to be broadly in line with the findings of the EC (2011) that most of the sectors that perform the majority of BERD have become more research intensive during the last decade[24]. At the same time, the weight of these same sectors in the EU economy has decreased thus provoking a counter balance effect. The EC (2011 conclude that there is still room for further increases in the research intensity of the high and medium high-tech industries across the EU. This conclusion appears particularly pertinent for Scotland given the overall decline in high-tech BERD expenditure noted above. Secondly, the structural composition of the economy is clearly a concern with the overall UK economy experiencing the sharpest structural declines in BERD intensity in the EU between 1995-2007 (EC, 2011, page 391). In this respect, the Scottish performance might be seen more positively with non-high tech sectors increasing their BERD expenditure. However what might be of more concern from a policy point of view is the lack of a rise in knowledge intensive services R&D or employment in Scotland. Although this trend is similar to that of the UK as whole, the Nordic countries and Ireland, Scotland had the lowest share of KIS employment in 2008[25] out of these benchmarked countries. In this context, the EC (2011) conclude that 'An economy can move towards more and larger knowledge-intensive sectors only with the emergence of new and fast-growing firms'.

To sum up, the challenge for Scotland appears to be two-fold: increase the R&D intensity of the high-tech manufacturing and knowledge intensive service sectors whilst maintaining and growing further the R&D, and more generally innovation, activity across a broader base of sectors and firms in the economy. This may be as much a question of ownership/corporate governance and critical scale of firms as it is any other factor. Data on the expenditure and employment on R&D performed by Scottish businesses according to the ownership and size structure of businesses in Scotland, suggest that only Scottish owned and other EU owned firms have increased R&D expenditure (annual average growth rate of 9.5% and 6.9% respectively) and employment (6.1% and 9.1% respectively) over the

[24] This is a hypothesis that would require further research to be confirmed.

[25] Source: Eurostat, Annual data on employment in technology and knowledge-intensive sectors by NUTS 2 regions and sex (1994-2008, NACE Rev.1.1)

period 2001-2010. During the same period R&D investment by firms headquartered in the rest of the UK fell by 14% and R&D employment by 19%. In terms of business size, the largest companies (400 employees and over) accounted for 56% of total BERD expenditure. However, within the services sector companies employing 0 to 99 employees accounted for 55% of BERD expenditure suggesting a more fragmented, and potentially sub-critical, ownership structure.

In the absence of access to other micro-level data sets that would allow us to explore further some of these issues, the final sub-section of this report considers whether the overall weak BERD performance of Scottish firms is having an observable effect on business growth and productivity.

2.2.2 Evidence on Scottish business growth and productivity

As has been noted above, investment in technology (notably via BERD) has been shown to contribute significantly to productivity in the business sector in the OECD. In order to further examine the issue of productivity differentials using more disaggregated data, we use a sample from the FAME database, which provides a range of data on firms with 20 or more employees across the UK. This allows a simple comparative analysis of productivity differentials to be undertaken showing how firms perform by postcode location. However, the data does not include all firms with 20+ employees and the data may not be totally representative of the firm population in all locations. Nevertheless it is one of the few sources of comparable data on firm performance given the restrictions imposed on use of business statistics by the ONS in the UK. The tables in Appendix C present some summary statistics on firm size and growth rates, as well as a labour productivity indicator.

In terms of sheer numbers, there are over 10 times as many firms in the FAME database extract (firms with 20+ employees) in London as there are in the next largest city, Glasgow. London is remarkably strong in terms of average productivity (that is, 'labour revenue productivity' defined as turnover/employee). However, Glasgow and Edinburgh have higher average productivities than all English cities (expect London). Ranking the four largest Scottish cities by average productivity yields the following ordering: first Glasgow, then Edinburgh, then Aberdeen, and then Dundee.

Looking at firm size (log_turnover and log_employees), there are no remarkable differences between firms in Scottish or English cities. Yet, in terms of the growth rate distribution, it can be observed that the mean growth rate (2009-10) is negative for most English cities included here, but positive for most Scottish cities. Notably, at the quantiles of the growth rates distribution for turnover and employee growth, Aberdeen sticks out as the only city with a nonzero median employment growth rate. Ranking the four largest Scottish cities by average employment growth (2009-2010), we observe the following list: first Dundee, then Aberdeen, then Glasgow, then Edinburgh. Although Dundee had a low average productivity, nonetheless it is experiencing relatively strong employment growth.

Moreover, Scottish cities generally have fewer fast-declining firms (see e.g. 1% and 5% quantiles) although the share of firms enjoying fast growth is roughly comparable to their counterparts in English cities (e.g. the 95% quantile).

Hence, despite the overall lower business R&D intensity and innovation activity that characterises the Scottish economy, the performance of Scottish businesses is not noticeably lower than their rest of UK counterparts. Despite the lower average R&D expenditure of Scottish firms, there is no obvious translation of this lower R&D intensity into a lower performance of Scottish firms (although to investigate this issue properly would require further in-depth analysis using sophisticated econometric techniques). However, we cannot rule out that prolonged under-investment in R&D, or more precisely a failure to increase the R&D intensity across the board in the manufacturing and services sectors, will have longer-term effects on productivity and employment growth.

2.3 Conclusion

To sum up, firstly, Scotland has an excellent performance with respect to university research. However, large (foreign-owned) firms are more innovative than the UK average and appear able to translate university research into productivity growth and superior performance (Harris et al, 2012). At the same time, SMEs are on average less innovative even if innovation activity expenditure and activity is much more widespread and intense than business R&D data would suggest. The evidence suggests that the barriers to innovation in smaller Scottish firms are more due to in-house capabilities to undertake R&D and innovation (non-technological) and that this may be linked to an over-emphasis on higher as opposed to vocational education. Focusing innovation policy on academic scientific research, and the commercialisation of research and knowledge transfer is not sufficient to overcome the 'capability failures' of SMEs and other bottlenecks in the innovation system.

Secondly, although HGFs are under-represented in high-tech sectors in Scotland, this is not at odds with evidence found for other countries. Henrekson and Johansson 2010 survey the literature and conclude (p227): "Gazelles exist in all industries. They seem not to be overrepresented in high-technology industries, but there is some evidence that they are overrepresented in services." Hence, the popular notion that HGFs are high-tech firms needs to be discarded.

Thirdly, there is little evidence suggests that academic spin-offs are a major driver of technology development nor are they contributing substantially to the renewal of the business base in Scotland (Harrison and Leitch, 2010). This limited growth of hi-tech firms compounds the fact, Levie (2009), that total entrepreneurial activity (TEA) in Scotland is lower than in other parts of the UK regions. However, we caution that, although entrepreneurship from universities may be a vital link in translating new technologies into high-tech start-ups, entrepreneurship in general is not expected to have significant economic benefits. The average entrepreneur is not a high-tech start-up. Furthermore, it appears that solo entrepreneurs account for an especially large share of SMEs in the UK compared to other OECD countries (Van Stel, 2012). Most entrepreneurship is low-impact entrepreneurship. In order to encourage entrepreneurship in the form of university spinouts, it is therefore not helpful to encourage entrepreneurship in general. Similarly, in order to encourage high-growth firms, it is not effective to encourage 'all firms' to grow.

3. Rethinking Innovation and Enterprise Policy in Scotland

3.1 High growth and high tech or scaling up and broadening of technological competence

This paper has reviewed the available evidence on the role of technology in driving economic development and applied it to the case of Scotland.

1. While the intensity of business R&D is partly dependent on the industrial structure of an economy and only captures part of the innovation process in many companies, there can be no doubt that the overall level of innovation intensity and activity in Scotland's business sector is sub-optimal. The low levels of business expenditure on R&D are as critical from a point of view of technology absorption within the existing businesses as from the point of view of contributing to a structural adjustment through the emergence of new (high growth) firms or sectors.

2. There is limited evidence that the perceived strength of the Scottish innovation system, that is the high level of higher education research expenditure and relatively high output and scientific impact, is directly contributing to overall Scottish economic growth, neither in terms of specific sub-sectors nor in terms of growing the Scottish population of high-growth firms. There are of course, a number of other ways in which HEIs contribute to regional economic performance and the supply of skilled graduates is obviously one of the most important, as well as being a main channel of knowledge diffusion into regional firms.

3. From a comparative perspective, the Scottish economy appears to be 'trapped' in a weak innovation and slower growth trajectory than neighbouring similarly sized Nordic countries and, even, that of Ireland (up to the financial crisis). Despite the extensive devolution of powers since 1999, the under-par Scottish performance seems to be partially due to it being embedded in the comparatively weaker UK innovation system. One reflection of this 'half-way' house may be the increasingly weak role that firms headquartered in other countries of the UK appear to be taking in investing in business R&D and innovation in Scotland. The lack of mid-sized companies in Scotland has been underlined in the past by the Royal Society of Edinburgh as a bottleneck in the innovation system. In this context, the potential for the Scottish Government to use demand side policies (innovative public procurement, legislative measures, etc.) or corporate tax incentives, etc. to boost growth or restructuring of Scottish headquartered firms or to attract innovation intensive foreign investors remains sub-optimal.

4. The evidence leads us to conclude that HGFs are not exclusively found in high-tech sectors. In fact, Mason and Brown (2010) find that HGFs are actually under-represented in high-tech sectors in Scotland, which is comparable to the broader findings from other countries that HGFs are over-represented in services but not over-represented in high-tech sectors (Henrekson and Johansson 2010). We should think of HGFs and high-tech firms as different categories, with a small intersection containing high-tech HGFs. Both of these categories play an important role in a modern economy – HGFs to create jobs and economic growth, and high-tech firms to generate productivity growth over the longer term.

5. We suggest that HGFs should not be seen as the 'be all and end all', but that they should be evaluated critically. First of all, it is notoriously difficult to pick out HGFs ex ante, which suggests that there is nothing much that can be done to provide support exclusively to HGFs. Policies aimed at HGFs are very blunt instruments. Perhaps the best that can be done is to identify the subset of firms that will never become HGFs, and eliminate those firms from the pool of potential recipients. Second, some HGFs might achieve fast growth in ways that have no clear economic benefit (for example, a HGF that grows purely by acquisition will have no impact on overall employment). Third, while we agree that growth is good, we question the mantra of 'the faster the better' and consider that some firms might go further in creating durable high-quality jobs by taking a steadier pace (think of fast-growing flimsy bamboo versus slow-growing strong oak trees).

6. Just as HGFs play an important, but limited role, so university spinouts are an exciting group of firms but their economic impact is small and should not be exaggerated. Evidence from both Scotland and internationally suggest that University spinouts cannot be relied upon as a significant source of high growth firms. However, their role in developing more 'disruptive' innovation and potentially fostering the growth of new emerging clusters of activity and

supporting longer-term structural adjustment cannot be ignored. The need for greater selectivity in supporting such spinouts is already recognised in Scotland based on the significant learning from the last decades of commercialisation support. As noted above, the difficulty is not so much to create a spinout as to grow one to become a large scale company generating further entrepreneurial activity in its wake. Embedding spinouts faster into existing 'value-chains' or using the leverage power of the Scottish Investment Bank to 'force' the merger of competing spinouts to create a larger, financially sustainable firm may be additional options in the future.

7. Entrepreneurs with prior industry experience tend to be higher quality entrepreneurs (Hvide, 2009). This suggests that individuals or teams spinning out of existing incumbent firms may enjoy high productivity (growth) and may grow fast and create jobs. However, this may be to the detriment of incumbent firms. It is not clear how public policy could play a role to encourage employees to set up spinoff firms. Furthermore, incumbent firms may well be hostile to such a policy (because they would have less trust in their employees), and it could even be that multinationals who seek to protect their IP would avoid setting up plants in Scotland. Therefore, we are not convinced that a policy that seeks to directly encourage spinoffs from incumbent firms would be a major source of high growth companies. However, this is not to say that there is not a greater role for 'companies of scale' to play in supporting entrepreneurs with innovative product ideas or novel forms of services, for instance, by mentoring, undertaking joint collaborative product development projects or helping smaller firms to piggyback into export markets.

8. One problem facing the Scottish innovation system seems to be that, despite world-class university research, indigenous Scottish firms seem to lack the absorptive capacity to benefit from this research (Harris et al, 2012). This problem of lack of absorptive capacity does not affect foreign firms in Scotland, however. A lack of absorptive capacity requires that the top quality research being done in universities be 'popularised' and diffused throughout the economy by balancing investment more towards adult education and intermediate skill levels, rather than remaining fixed on the top percentiles of the university population.

Given these findings, we argue that there is a need to adjust the current Scottish enterprise and innovation policy to achieve a step change in the contribution of technological development and absorption to economic growth.

3.2 Scottish innovation and enterprise policy in a comparative perspective

Scottish innovation and enterprise support policies have a relatively long history and indeed the precursor (the Scottish Development Agency was established in 1975) to the current enterprise agencies had established a strong track record internationally for attracting inward investment by the time it was dissolved in 1994 (Halkier 1992). However, by the mid-1990s, it was clear that the 're-industrialisation' of Scotland through inward investment of screwdriver plants was not a sustainable source of growth as such subsidiaries of MNE moved on to countries with 'cheaper labour'. Hence, the aspiration to create a 'Silicon Glen' through inward investment was replaced by a stronger focus in policy on indigenous growth (while maintaining through the enterprise agencies and Scottish Development International a focus on attracting higher-value added foreign investment). During the 2000s, public policy also became strongly focused on high-tech sectors as a source of new high indigenous ventures (see Brown and Mason, 2012).

The reorientation to indigenous growth is driven by two-pronged strategy aimed at, on the one hand, supporting the development of key sectors and existing 'growth' companies (Scottish Government's Economic Strategy 2007, 2011); and, on the other, by a strong emphasis on 'commercialising' the research base through, notably university spin-offs. The 1996 "Commercialisation Inquiry", by Scottish Enterprise and the Royal Society of Edinburgh, led to a range of new support measures being launched to foster academic spin-offs, including; Enterprise Fellowships, Proof of Concept, Co-investment Funds, etc. Scotland is often cited as positive example of a 'regional' approach to seed/angel capital and the consolidation of equity financing instruments in the Scottish Investment Bank, etc. would seem on paper to ensure that potential high-growth companies in Scotland should be able to attract 'smart money'.

This dual strategy for growing existing high potential firms and creating and growing new 'tech' based firms is complemented by efforts to promote Scotland as a base for undertaking advanced technology development in specific fields. Initiatives such as the Saltire prize, renewable energy investments, the low carbon strategy, etc. are aimed at enabling Scotland to reap the benefits of both academic research excellence, natural resource potential and industrial specialisation (or re-positioning, for instance, applying engineering knowledge from the oil and gas sector to offshore renewable development). There are early signs that this form of 'smart specialisation', to use the European Commission's latest buzzword[26], may be generating an impact. Such signs include the recent decision to locate the UK's Green Bank in Edinburgh and the UK Offshore Renewable Energy Catapult in Glasgow as well as major inward investment into R&D centres of multinational energy firms.

In short, the Scottish 'policy-mix' (complemented by some UK wide measures, notably the Technology Strategy Board and R&D tax credits) can be considered relatively sophisticated compared to most other EU 'regions' and even the Irish and Nordic cases used as benchmarks for this report. Yet at the same time, policy-makers and agencies continue to be faced by a series of challenges that the current policy framework may at best be enabling Scotland to catch-up gradually or hold its ground. A more sustained upward shift in business growth rates or to innovation performance would almost certainly require a more radical restructuring of the business base both in terms of activity, investment, ownership and demographics (RSE 2011 pointed to the lack of medium-sized firms in Scotland as a major weakness.)

What can Scotland learn from the policies implemented in the two main Nordic comparators, discussed earlier in this report, which face very different challenges in terms of sustaining innovation and economic well-being at high levels. A common issue in both countries is that despite education systems with an excellent reputation, science, technology and engineering skills are seen as a 'weak' point that may either undermine technology development nationally or lead to the off-shoring of existing corporate R&D activities (Swedish case).

The policy context and response to the 'Norwegian paradox' has clear parallels to the 'Scottish 'conundrum'. Norwegian policy-makers, while accepting that part of the 'innovation deficit' can be explained by the industrial structure, express strong concerns that the economy is not sufficiently innovative to be viable in the longer term. Hence, it is a key, long-term objective of Norwegian policy to expand the share of innovative, knowledge-intensive activities in the economy. Scordato (2012) notes that 'as the majority of large Norwegian companies have tended to fall back on their core business areas', the main actors in emerging innovation areas are SMEs, often spin-offs from major companies or research institutions. These companies struggle to succeed in the commercialisation phase, and do not succeed in growing into medium large companies.

As in Scotland, there is a clear focus on restructuring the economy through both a focus on strategic sectors and technology development and business investment in new technologies related to environmental challenges. However, in recognition, that many of the national programmes aimed at supporting technology development were failing to reach regional small firms, a major new measure was launched in 2009 in the form of Regional R&D Funds. These funds will be administered in seven regions (each grouping a number of the counties, equivalent to Scottish local authorities) by a public-private-higher education partnership based on a prior identification of strategic priorities for the region. The priorities have been set through the Programme for Regional R&D and Innovation (VRI) that is designed to promote greater regional collaboration between trade and industry, R&D institutions and the government authorities, and to establish close ties to other national and international network and innovation measures such as the Arena programme, Norwegian Centres of Expertise (NCE), etc. While it is still too early to talk about robust results, Asheim (2011) argues that this is a relatively unique attempt to implement an innovation policy at regional level by apply the doing–using–interacting (DUI) mode of innovation[27], better suited to non-R&D based economies.

[26] Smart Specialisation is a strategic approach to economic development through targeted support to Research and Innovation (R&I). It will be the basis for Structural Fund investments in R&I as part of the future Cohesion Policy's contribution to the Europe 2020 jobs and growth agenda. More generally, smart specialisation involves a process of developing a vision, identifying competitive advantage, setting strategic priorities and making use of smart policies to maximise the knowledge-based development potential of any region, strong or weak, high-tech or low-tech.

[27] The D(oing), U(sing) and I(nteracting) mode of innovation relies on informal processes of learning and experience-based know-how. The DUI mode is a user- or market-driven model based more on competence building and organisational innovations and producing mostly incremental innovations. Such a mode of innovation is typically found in non-R&D-based economies.

The Swedish innovation system is dominated by an internationally competitive higher education sector and a small number of major Swedish (increasingly foreign owned) firms. Sweden is viewed internationally as being amongst the top performers in innovation but nationally the inability to transform the research base into economic growth and weak entrepreneurial activity leads commentators to view the innovation system as being somewhat sclerotic (Melin et al, 2012). The Swedish innovation and high-tech growth policies are among some of the most sophisticated in Europe and are managed by a specific agency responsible for 'innovation system' (VINNOVA). Yet, as Melin et al (2012) note the policies rolled out to try and commercialise the strong research base have not borne fruit (although a number of new measures have been recently introduced to try and provide more comprehensive support). Where the Swedish policy stands out from Scotland is in the focus on collaborative partnerships either through instruments such as the competence centre model (consortia of firms and university research units) working together on a technology road map; or in the VINNVÄXT programme which has supported over a decade regional 'triple-helix' partnerships to invest in developing 'competitive research and innovation environments in specific growth areas'. The VINNVÄXT projects are characterised by their long term nature (a decade of funding) and an emphasis on a strong regional leadership that promotes industrial renewal through applying technology solutions[28].

3.3 Future policy options

Our findings lead us to the conclusion that Scottish innovation and enterprise policies need to be realigned to reflect the main barriers to growth and innovation. The current suite of policies does not do enough to tackle a number of key obstacles to a step change in Scottish innovation and productivity growth performance. There is a need to adjust the balance of policy towards increasing innovation activity in existing companies rather than on creating new technology based firms. This calls for a greater integration of innovation and business support policies with education and training policies in order to increase the levels of human capital and tackle the weak absorptive capacity in firms.

A large part of the current Scottish policy intervention is based on a somewhat ill-defined concept of growth companies, given our findings that it is difficult to identify ex ante such firms, and on the funding of if not 'individual innovation events' then at least the individual innovation projects of specific companies. The Scottish 'innovation conundrum' will not be resolved by further strengthening either commercialisation through spin-offs or knowledge transfer and brokering actions. We are aware that the Scottish Funding Council is extending support for 'industry-led' innovation centres for the key strategic sectors, and this stronger focus on demand side needs in knowledge exchange is welcome. Hence, we are not suggesting to throw the baby out with the bath waters and halt all efforts to 'exploit' the academic knowledge base. Rather, we consider that the main barrier is the lack of absorptive capacity on the business side which suggests the need to invest more in initiatives that seek to recruit and place 'innovation managers' in firms, such as the graduate placement programme of Highlands & Islands Enterprise.

Combining the observations that Scotland lacks enough mid-size companies with the weaker innovation activity of small companies, suggests the need to switch from grants for individual firms that are likely to favour 'already R&D ready' firms and reinforce efforts to increase the number of Scottish indigenous, notably mid-sized firms, undertaking internal R&D. We think this could be achieved in several ways: firstly, by shifting the balance of funding to more collaborative industry led R&D partnership (along the lines of the successful 'competence centre' programmes that have been tested in a number of EU countries). This would allow firms to share the burden of investment but also skilled staff (the lack of which appears to be a more important barrier to Scottish small firms than across the UK as a whole). Larger Scottish firms as well as multinationals with operations in Scotland should be encouraged to play an active role in such consortia in order both 'mentor' smaller partner firms and facilitate their access to technology developed 'elsewhere'.

Secondly, we consider that, on paper, the Food Innovation Network may be the type of tailored initiative required to boost technology uptake and diffusion in specific industry sectors. The

[28] A 2007 evaluation found that the VINNVÄXT projects were performing well in general and that there is good potential for future growth from these initiatives. See: http://bit.ly/OJohT3

enterprise agencies should explore whether there is scope for expanding such support to other 'low-tech' sectors with the aim of boosting the number of innovation active firms.

Finally, we suggest that a regional innovation challenge fund is created that would aim to replicate the success of certain sectoral industry leadership groups in driving value added or export growth. The aim would be to draw up action plans to support cross-sectoral co-operation or technology absorption in regional economies. These partnerships could be linked to the enterprise areas recently established by the Scottish Government or draw on the experience of projects such as the South of Scotland Innovation System. Regional partnership bidding for funding would be required to set a number of goals in terms of business growth, innovation activity, etc. of participating businesses.

3.4 Further topics for research

We have explored tentatively issues around the importance of the sectoral composition of the Scottish economy and business R&D intensity. Due to data limitations and time available we were not able to calculate an adjusted BERD rate but further developing this line of analysis may help to explain why Scottish business productivity performance is better than might be expected given the intensity of business R&D. Similarly, we believe that it would be instructive to inform future policy initiatives to examine the relation between R&D/innovation expenditure and employment growth.

More research into the relationships between technology, university spinouts, high-growth firms, and economic growth is needed. In particular, we need to improve our understanding of why indigenous Scottish firms have such a low absorptive capacity – little is known about the determinants of absorptive capacity, and how a lack of it can be remedied. Another potential area of research could be to explore if a link exists between absorptive capacity and firms that have gone through a phase of high-growth to become export-intensive or 'companies of scale'. For instance, does having an international outlook increase a firms ability and willingness to absorb technologies and intelligence to exploit new market opportunities?

One cost-effective way to obtain this research, we suggest, would be to fund a programme of PhD and post-graduate research into business growth and innovation in the Scottish economy. PhD students will presumably be glad to work on the available data at low cost if it means they can publish their research in leading academic journals. Furthermore, many who pursue careers in academia tend to continue the research started during their PhDs even many years afterwards. At present, many PhD students work on foreign data (e.g. US data), to the dismay of UK politicians, because data on the UK is sometimes difficult to obtain. This is not necessarily because of a 'conspiracy of US-based academic journals,' as some suggest, as much as the relative difficulty of obtaining access to high quality official data in the UK. Scottish Government Ministers could try to make data from the UK Office of National Statistics (ONS) more freely available to researchers based in Scottish higher education institutes.

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Appendix B Scottish Government data clarifications

The following data was kindly provided by the Scottish government:

- Data from SABS (Scottish Annual Business Statistics) for 2001-2009 was provided on a SIC 2003 basis. Note that Annual Business Survey (ABS) was sampled on a SIC 2007 basis from 2008 onwards and there was also a change in the sampling framework[29]. This may impact on the time series data produced;
- Data from BERD (Business Enterprise Research and Development), 2001-2010: Scottish expenditure data on a NACE rev 1.1 basis, subject to the above caveat. BERD data were supplied at aggregate level only for the high-technology manufacturing industries, medium-high-technology manufacturing industries and high-tech knowledge intensive services categories. Whereas, SABS was supplied at SIC level within these categories, disclosure allowing.

Furthermore some extra caveats include the following:

- Within industry 24.14 (Manufacture of other organic chemicals), a downwards revision has been made to the turnover figure for reference year 2008 which affects turnover and GVA figures in the table. One group had previously included its turnover generated in other European countries. The error has been corrected for the 2008 data onwards;
- In SIC 24 (Chemicals) excluding SIC24.4, Oil price changes can have a significant impact on this sector's figures;
- In the datasets used there are a few disclosive cells within the three overall totals. There was no way to avoid this due to disclosure by deduction with data already published. It was however sufficient information for the purpose of this study.

[29] See Sample Design section in Methodology in Scottish Annual Business Statistics website for more information <http://www.scotland.gov.uk/Topics/Statistics/Browse/Business/SABS/Methodology>

Appendix C FAME data on productivity and employment by major city

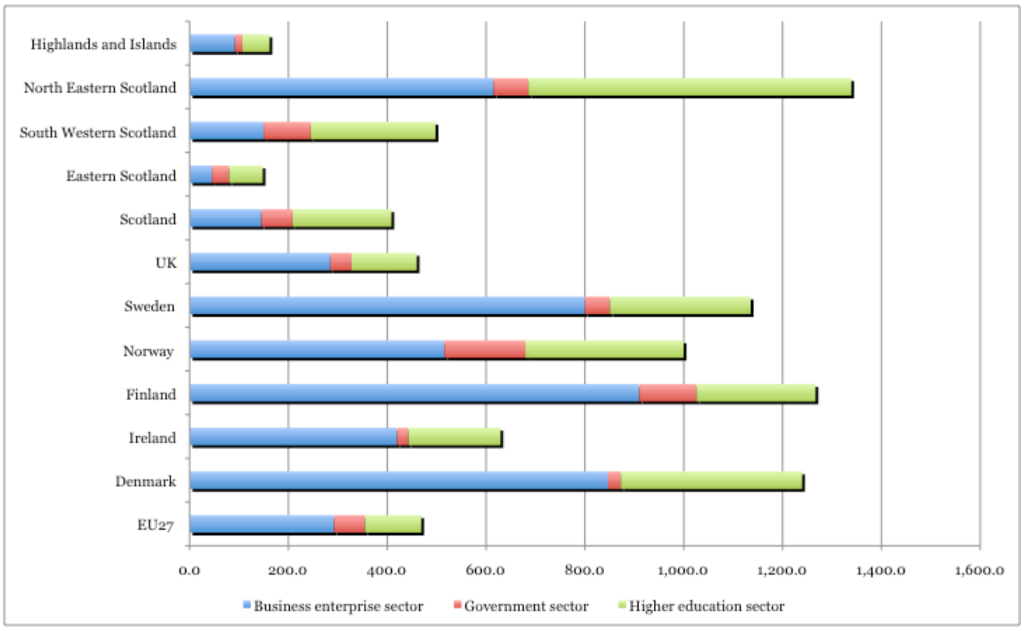
	Obs	Mean	Std. Dev.	Min	Max
Productivity					
London	11169	590.449	8439.019	-13.8	694476.2
Birmingham	779	205.6101	515.2986	0.7	11364
Leeds	801	215.6229	536.397	-0.33333	6470.107
Sheffield	434	166.7712	226.7474	3.868056	1913.758
Bradford	257	215.9322	394.1968	4.152174	5668.828
Liverpool	435	200.7968	433.2956	0	5873.75
Glasgow	874	248.589	1608.612	0.2575	39727.52
Edinburgh	575	235.2849	596.8466	5.181818	8975.018
Aberdeen	446	209.3787	334.229	0.6	3595.875
Dundee	109	142.4506	312.6755	2.294118	3066.348
Log turnover					
London	11996	9.285614	1.920877	0	19.30247
Birmingham	821	9.245727	1.726578	1.386294	14.72657
Leeds	831	9.226345	1.710317	1.098612	16.83823
Sheffield	451	8.9359	1.688715	3.044523	14.79684
Bradford	266	9.469635	1.812346	3.465736	16.6176
Liverpool	455	8.976729	1.848319	2.079442	14.45931
Glasgow	904	9.04915	1.784178	0	15.78031
Edinburgh	613	8.940767	1.933156	3.044523	16.737
Aberdeen	469	9.251404	1.499206	1.098612	15.67636
Dundee	115	8.643733	1.652873	5.049856	12.75014
Log Employees					
London	11682	4.364583	1.56564	0	12.61926
Birmingham	808	4.596647	1.448056	0	10.9144
Leeds	827	4.571268	1.477169	0	12.05843
Sheffield	449	4.372809	1.291892	0.693147	9.350798
Bradford	262	4.61828	1.491061	0	11.79112
Liverpool	443	4.480528	1.395618	0	9.693137
Glasgow	885	4.608464	1.318016	0.693147	10.98292

Appendix C continued: summary statistics and key quantiles of the growth rates distribution.

	Obs	Mean	Std. Dev.	Min	Max	1%	5%	10%	25%	median	75%	90%	95%	99%
Growth Turnover														
London	10629	0.021	0.675	-9.850	8.772	-2.455	-0.599	-0.312	-0.082	0.042	0.179	0.403	0.642	1.647
Birmingham	725	0.015	0.519	-6.622	2.574	-2.793	-0.493	-0.296	-0.063	0.043	0.176	0.375	0.503	0.864
Leeds	735	-0.004	0.639	-7.204	7.142	-1.789	-0.649	-0.309	-0.089	0.021	0.136	0.303	0.463	1.681
Sheffield	414	-0.012	0.493	-4.736	2.323	-1.790	-0.605	-0.266	-0.085	0.014	0.152	0.305	0.491	0.945
Bradford	234	0.003	0.446	-4.442	1.707	-1.883	-0.394	-0.200	-0.037	0.048	0.150	0.279	0.426	0.702
Liverpool	400	-0.001	0.534	-5.524	4.046	-2.464	-0.462	-0.235	-0.072	0.028	0.157	0.282	0.467	1.063
Glasgow	804	0.039	0.484	-3.536	5.678	-1.260	-0.458	-0.270	-0.062	0.026	0.137	0.310	0.478	1.323
Edinburgh	554	0.011	0.534	-5.121	3.788	-1.457	-0.617	-0.368	-0.078	0.020	0.121	0.323	0.557	1.914
Aberdeen	423	-0.018	0.623	-8.349	4.325	-1.236	-0.601	-0.326	-0.114	0.025	0.166	0.350	0.465	1.096
Dundee	104	0.036	0.368	-1.392	2.391	-0.692	-0.458	-0.220	-0.085	0.029	0.117	0.291	0.500	1.341
Growth employees														
London	10681	-0.036	0.564	-8.770	6.551	-2.686	-0.511	-0.258	-0.088	0.000	0.093	0.243	0.395	1.162
Birmingham	753	-0.060	0.546	-6.264	2.438	-2.565	-0.502	-0.246	-0.089	0.000	0.069	0.197	0.301	0.836
Leeds	749	-0.074	0.607	-6.285	4.498	-2.391	-0.561	-0.297	-0.100	0.000	0.059	0.184	0.307	0.821
Sheffield	429	-0.017	0.373	-2.959	2.715	-1.825	-0.318	-0.194	-0.084	0.000	0.070	0.208	0.342	0.775
Bradford	239	0.029	0.582	-3.209	4.155	-1.946	-0.321	-0.183	-0.056	0.000	0.085	0.185	0.391	3.672
Liverpool	406	-0.040	0.573	-4.883	4.677	-2.197	-0.452	-0.233	-0.075	0.000	0.072	0.172	0.313	0.887
Glasgow	832	0.000	0.356	-2.979	4.988	-1.066	-0.331	-0.185	-0.066	0.000	0.077	0.193	0.326	0.633
Edinburgh	554	-0.023	0.417	-3.578	4.248	-1.526	-0.386	-0.241	-0.099	0.000	0.069	0.182	0.306	0.842
Aberdeen	420	0.009	0.536	-4.350	2.927	-2.303	-0.310	-0.213	-0.067	0.007	0.098	0.235	0.378	2.351
Dundee	101	0.038	0.401	-0.785	3.546	-0.503	-0.220	-0.126	-0.070	0.000	0.071	0.165	0.348	0.802

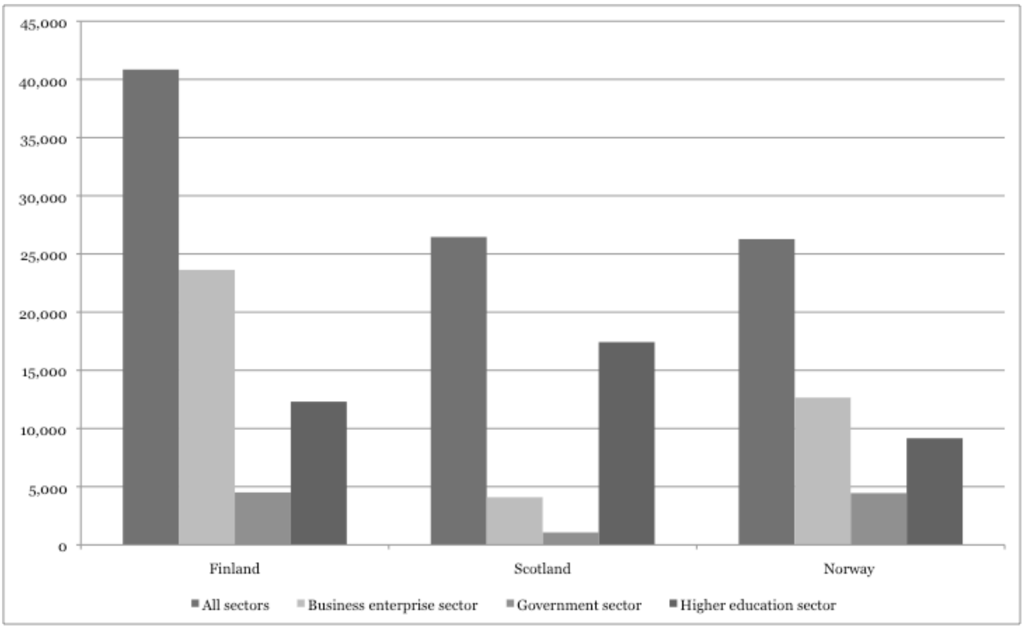
Appendix D Selected statistics on the Scottish research and innovation system

Figure 11: R&D expenditure per capita (in euro) by sector performance (2009)



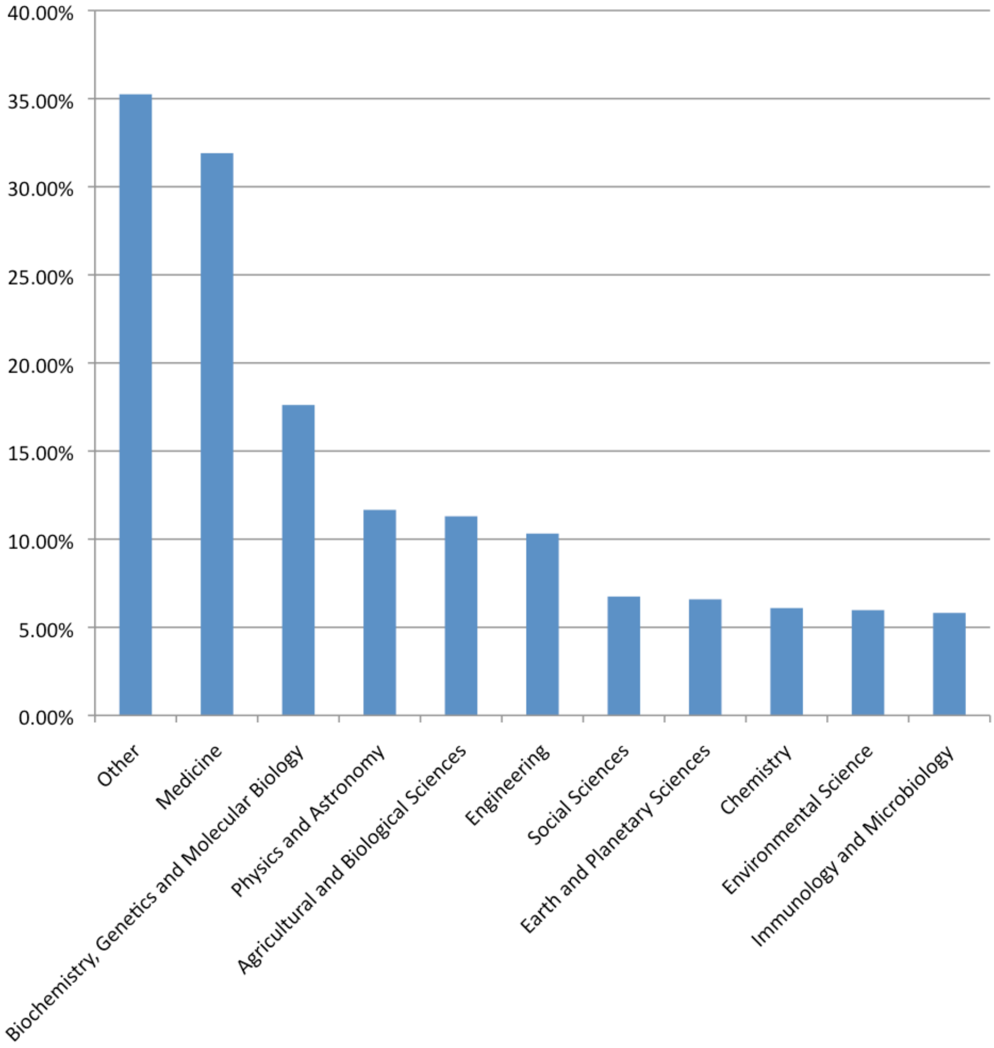
Source: Eurostat, calculations authors

Figure 12: researchers per sector 2009, Scotland compared to Finland and Norway



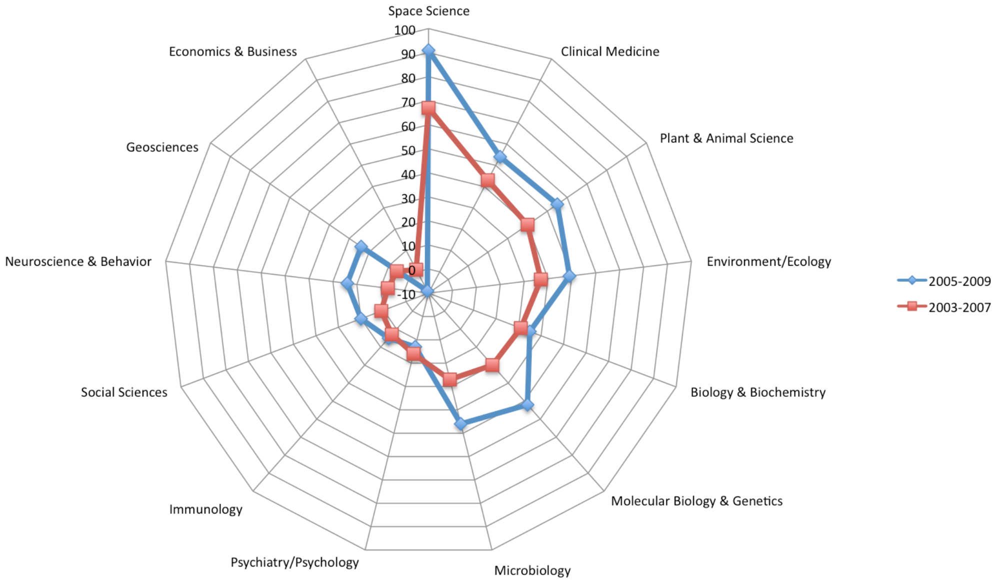
Source: Eurostat, calculations authors

Figure 13: Scottish scientific output by scientific field (2000-2011)



Source: SCOPUS, calculations authors

Figure 14 Scotland - Relative citation impact compared to the world average



Source: Science Watch, calculations authors

Appendix E : Scottish universities ranking out of 150 UK universities for spinouts/start-up companies.

Rank	Name	Region	Companies
1	University of Edinburgh	Scotland	244
2	University of Cambridge	East	141
3	Imperial College London	London	91
4	University of Oxford	South East	79
5	University of Manchester	North West	78
6	University of Strathclyde	Scotland	72
7	Newcastle University	North East	50
8	Queen's University Belfast	Northern Ireland	46
9	University of Bristol	South West	44
10	University of Glasgow	Scotland	43
	...	...	...
14	Heriot Watt University	Scotland	35
16	University of Aberdeen	Scotland	32
19	University of Dundee	Scotland	28
30	University of St Andrews	Scotland	18
37	Edinburgh Napier University	Scotland	13
38	Robert Gordon University	Scotland	12
51	University of Abertay Dundee	Scotland	5
54	Glasgow Caledonian University	Scotland	4
57	UHI Millennium Institute	Scotland	4
64	Queen Margaret University	Scotland	2
83	University of Stirling	Scotland	1
93	Glasgow School of Art	Scotland	0
113	Royal Scottish Academy of Music & Drama	Scotland	0
116	Scottish Agricultural College	Scotland	0
141	University of the West of Scotland	Scotland	0

NOTES: All companies of all ages associated with the university or HEI, whether true spinouts (based on IP owned by the university), or start-ups formed by university staff or graduates, and some started by students or third parties for which we do not yet have full information. These numbers should not therefore be taken as the relative success of the university in creating spinouts. Source: http://www.spinoutsuk.co.uk/listings/university-listings/Default.aspx

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