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Inside the high-tech black box: A critique of technology entrepreneurship policy

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ABSTRACT

Promoting new technology-based firms is the cornerstone of technology entrepreneurship policies in advanced industrial economies. Drawing on quantitative and qualitative empirical evidence from the UK, this paper provides a critique of these policy frameworks. The aggregate analysis shows that vast majority of these firms are micro firms, a small minority of whom grow rapidly. The paper then highlights the incongruence between the nature of these firms and the public sector technology policies designed to support them. The qualitative data reveals that typically these firms are corporate rather than university spin-offs; most do not undertake large amounts of in-house R&D; most do not have protected IP; and only a small minority are VC-backed. Most derive their main competitive advantages from open innovation sources such as relationships with end-users and customers. The paper offers suggestions for how policy could be recalibrated to better reflect the requirements of local entrepreneurial actors and the types of support required by most high-tech SMEs.

1. Introduction

In recent years, both the OECD and the European Union have strongly endorsed the view that innovation is a key driver of economic growth (European Commission, 2010; OECD, 2010a; Flanagan et al., 2011; Dolfsma and Seo, 2013; Cox and Rigby, 2013; Mazzucato, 2013). A core component of technology policy since the 1990s has been encouraging the formation and growth of new technology based firms (NTBFs) (Autio, 1997; Storey and Tether, 1998; Almus and Nerlinger, 1999; World Economic Forum, 2011). Despite the fact that these firms comprise a small proportion – around 15% – of the overall population of SMEs within most advanced economies, policy makers view these firms as a disruptive and dynamic part of their entrepreneurial ecosystems (OECD, 2000; Mason and Brown, 2014). For many policy makers it has become something of a 'stylised fact' that high-tech industries are a panacea for boosting growth within modern economies (Coad and Reid, 2012). Indeed, there are very few government strategies that do not adhere to the mantra that 'technology drives growth'.

Consequently, at both national and regional levels (Storey and Tether, 1998; Asheim et al., 2011; Coad and Reid, 2012), the promotion of technology based firms (henceforth TBFs) has become a central tenet of public policy within advanced industrialised economies during the last thirty years. This focus has been particularly pronounced in 'liberal market economies', such as the Australia, Britain, Canada and the US (Hall and Soskice, 2001) and has manifested itself in a fairly homogeneous set of policies designed to promote TBFs. This 'one size fits all' approach is often strongly predicated on a linear view of innovation and has typically resulted in a range of generic policy measures across OECD countries such as higher education research commercialisation policies, strong support for university spin-offs, public sector co-investment schemes, science parks, cluster policies and technology incubators (OECD, 2010b; House of Commons, 2013). Firm-based support is dominated by transactional forms of innovation support in the shape of innovation grants and tax credits.

This policy focus is underpinned by strongly held and interlinked assumptions. First, it became the received wisdom during the second half of the twentieth century that "one of the greatest engines fostering economic growth in the global economy was high-technology industry" (Frenkel, 2012, p. 724). Second, dynamic regional economies like Silicon Valley were seen as evidence of the transformative effect that technology clusters can have on regional economies (Saxenian, 2006; Hospers et al., 2008) by accelerating the growth of technology start-ups (Feldman et al., 2005; Delgado et al., 2010). Third, technological development is an important determinant of entrepreneurial opportunity (Eckhardt and Shane, 2011) which is often exploited

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by 'disruptive' new starts rather than incumbent firms (Shane and Stuart, 2002). Finally, despite the fact that technology-based firms do not disproportionately contribute towards the overall stock of high growth firms (Brannback et al., 2010; Bleda et al., 2013) they are strongly targeted within industrial and entrepreneurship policy frameworks (Brown et al., 2014; Coad et al., 2014).

These views have become well established because there has been a lack of research to identify the nature of high-tech firms which are often viewed as something of a 'black box'. This paper challenges some of these 'stylised facts' which have become entrenched in policy circles about the nature of TBFs and how they should be supported. There is a paucity of research that has closely examined the entrepreneurial dynamics and specificities of high tech firms. The empirical focus of this research is Scotland. This provides a suitable empirical 'case' owing to the strong emphasis on promoting high tech firms both within Scottish and UK technology entrepreneurship policies. By explicitly examining the nature of TBFs within the Scottish regional innovation system (RIS) we show a clear 'mismatch' between the nature of these firms and the types of public policies deployed to foster and support them. The paper addresses this issue by posing the following research question: *what are the characteristics of technology-based firms and how effective is current technology policy deployed to generate and support them*?

Although the empirical focus is Scotland, on account of the high degree of policy isomorphism in the field of technology and entrepreneurship policy (OECD, 2010b), these findings have wider relevance for other regions and countries. Despite increasing lip-service towards more systemic approaches to innovation (Warwick, 2013), the paper argues that the dominant logic and rationale for technology policy "is still primarily shaped by market failure justifications" (Dodgson et al., 2011, p. 1147). This type of approach ignores geographical and institutional context and, specifically, the past and present economic characteristics and consequent resource mix of different regions and countries which constrain the types of policies that are both feasible and desirable. The findings will therefore have a strong resonance for other economies with similar policy frameworks across the OECD. The focus within the paper is exclusively on high-potential new ventures and the policies designed to enhance them rather than the full spectrum of enterprise policies.

2. Mapping the contours of current technology policy

Technology policy in advanced capitalist economies can be categorised as either 'mission' oriented or 'diffusion' oriented (Ergas, 1987). In mission-oriented countries technology policy is often focused around big science projects which aim to reap major scientific discoveries in cutting edge technological areas such as aeronautical engineering and microelectronics. The countries which best exemplify this approach are the UK, the US and France (Ergas, 1987). The co-creation of Concorde by the British and French governments is a good example of this kind of mission-oriented approach within technology policy (Mustar and Laredo, 2002). In diffusion-oriented countries, on the other hand, the primary goal of technology policy is to create a broad-based approach so that the firms within their economies can adapt to changing technologies. In these economies much greater emphasis is on fostering networks of SMEs and creating linkages between these firms, and public and quasi private technology-transfer institutions. This relational, or 'bricolage', approach towards innovation (Spencer et al., 2005, p. 325) is often underpinned by a strong corporatist institutional framework consistent with so-called 'coordinated market economies' (Hall and Soskice, 2001). Countries which have adopted this approach to technology policy include Germany, Sweden and Switzerland (Ergas, 1987).

While, arguably, the onset of globalisation and inter-governmental learning has eroded the distinctiveness of these dichotomous approaches, differences nevertheless remain (Spencer et al., 2005). Indeed scholars continue to find quite distinctive institutional differences between countries like the UK and Germany where the former concentrates heavily on producing 'radically innovative' firm competences while the latter focus on 'competency enhancing' human resource practices (Casper and Whitley, 2004). Indeed, the strong policy focus on creating NTBFs is consistent with the "breakthrough approach to technological entrepreneurship" embedded within mission-oriented economies (Spencer et al., 2005, p. 325). Spurred on by the success of Silicon Valley in California, governments around the world, especially in 'mission' oriented countries, have increasingly focused on promoting knowledge based starts within their technology policies (Acs et al., 2009; Delgado et al., 2010; Lerner, 2010). This is evident in the huge upsurge in public policy programmes over the past 20 years aimed at developing high-tech, high growth starts (Tether, 1997; Storey and Tether, 1998; Almus and Nerlinger, 1999; Mason and Brown, 2013).

A central thread running throughout the majority of these policy approaches is the belief that TBFs predominantly arise from the commercialisation of university generated intellectual property (IP) through the establishment of university spin-outs (USOs) (Dahlstrand, 1997). USOs are viewed very positively by policy makers as an "economically powerful subset of high technology start ups" (Shane, 2009, p. 1) that provide a key conduit for the creation of new high-tech firms (Lockett et al., 2005; Rothaermel et al., 2007; Harrison and Leitch, 2010). However, the evidence indicates that very few USOs grow and many remain very small (Targeting Technology, 2008; Harrison and Leitch, 2010). Indeed, recent comparative research of USOs and company spin-offs (CSOs) found that the performance of CSOs in terms of sales growth and survival rates is considerably higher (Wennberg et al., 2011). These findings have led some to claim that the prominence given to spin-offs in the transfer of university research to the market place and has been greatly exaggerated (Perkmann and Walsh, 2007; Harrison and Leitch, 2010).

While public policy has strongly focused on producing 'new' high-tech firms (Brown and Mason, 2012a), established TBFs have also been heavily supported. Indicative of this is the central and enduring role given to transactional R&D support across most OECD economies (OECD, 2010a). Despite a lack of concrete evidence, policy makers at various spatial levels view R&D support as a central mechanism for fuelling productivity growth within their respective jurisdictions (Dosi et al., 2006; Coad, 2009; Mazzucato, 2013). While the different interventions and tools adopted to support innovation are diverse and multifaceted, a number of common features unite these policy approaches. Indeed, most advanced economies now appear to have the same universal 'toolkit' of grants, soft loans and tax incentives for supporting innovation (Lerner, 2010; Currid-Halkett and Stolarick, 2011).

In the main, the most high profile and resource-intensive forms of support are direct grant-based mechanisms which support capital expenditure for R&D in SMEs. As Fig. 1 shows, these direct forms of assistance are the dominant forms of policy support across the OECD, especially in the US, France, Korea and Spain. Research has typically found quite low levels of additionality from these kind of approaches on account that they 'crowd-out' private investment (Feldman and Kelley, 2006) and generally fail to generate high growth firms (Coad and Reid, 2012; Mason and Brown, 2013). This has prompted a shift in recent years towards a more pervasive use of indirect forms of support such as R&D tax

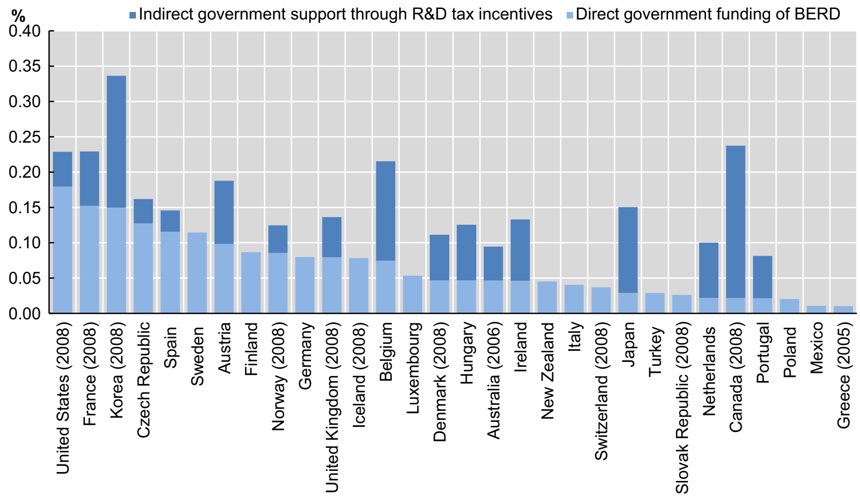

Fig. 1. Direct and indirect government funding for R&D business and tax incentives, 2008.
Source: OECD (2010c).

incentives across the OECD (OECD, 2010c), especially in Canada, Japan and Korea. More than 20 OECD countries now use these fiscal incentives to stimulate R&D (OECD, 2010c). The use of such incentives is also evident at a sub-national level. For example, there are now 40 states in the US which offer tax incentives for R&D (up from 35 in 1996) (Miller and Richard, 2010). Recently, the Netherlands introduced tax incentives for corporate researchers, which was found to have greater 'additionality' than income-based R&D tax credits (Mazzucato, 2013).

These types of support are largely offered to high tech, science-based SMEs which undertake intra-mural R&D and tend to be concentrated in certain industrial sectors (Brown et al., 2014). Recent analysis of the innovation support policies in Scotland revealed that around three quarters of this support goes to firms in just three key high-tech sectors: electronics, life sciences and energy (Brown and Mason, 2012a). Indeed, innovation support programmes are often targeted at more sophisticated science-based firms which undertake formalized R&D and have knowledge links to universities rather than the majority of SMEs in traditional sectors with more ad hoc innovation processes (Toedtling et al., 2009).

There are also important but much less overt forms of support which substantially benefit TBFs. These 'hidden' forms of support are often horizontal policies aimed at enhancing the entrepreneurial business climate within economies (Block, 2008). A particularly good example of these 'hidden' policies is venture capital which is viewed as a central component in innovation systems (Lerner, 2010; Kenney, 2011). In recent years, there have been concerted attempts by policy makers in advanced economies to increase the supply of early stage risk capital through the establishment of public sector venture capital funds, 'hybrid' funds, fund-of-funds, support for business angels (notably tax incentives) and co-investment funds (Murray, 2007; Gompers and Lerner, 2010; Lerner, 2010). Here again, the evidence indicates that this form of intervention has been narrowly focused. For example, analysis of data from the Scottish Co-Investment Fund, established to invest alongside business angel groups, reveals that three sectors (enabling technologies, life science and renewable) together account for 80% of all expenditure by value (Scottish Enterprise, 2012). By the very nature of this kind of equity-based finance, much is specifically targeted towards risky high-tech businesses where debt finance is inappropriate (Gompers and Lerner, 2010). The evidence suggests that this type of policy intervention has been largely ineffective (Lerner, 2010).

3. Systemic innovation policy: old wine in new bottles?

While most of policy approaches remain strongly wedded to the traditional linear view of innovation where 'market failure' arguments take centre stage, scholars and policy makers have increasingly embraced newer 'evolutionary' methods of conceptualising the role of innovation within contemporary economies (Nelson and Rosenberg, 1993). Instrumental in this respect is the role of systemic theoretical approaches towards understanding innovation (Lundvall, 1992; Metcalfe, 1997; Sharif, 2006; Dodgson et al., 2011; Warwick, 2013). Within this evolutionary paradigm, innovation is viewed as a non-linear, relationally 'embedded' and geographical bounded phenomena (Granovetter, 1985; Morgan, 1997; Gertler, 2010) where institutional actors (Gertler, 2010) and government policies often intermingle to play a central role in shaping innovation patterns (Freeman, 1995, 2002; Dodgson et al., 2011). Much of this early theorising by innovation scholars was based on empirical research within a number of 'diffusion' oriented or coordinated market economies such as Austria, Germany and Scandinavia (see Freeman (1995); Cooke et al. (1997)).

For some time now, organisations such as the OECD, European Commission and UNCTAD have embraced national innovation systems (NIS) as a key 'analytical concept' for understanding how knowledge is generated, disseminated and exploited (Sharif, 2006; Lundvall, 2007; Bergek et al., 2008). According to some, this kind of systems thinking has been "infusing the policy debate" on technology and innovation policy (Dodgson et al., 2011, p. 1147). Some scholars maintain the adoption of a systemic approach is "helpful for designing policies which will nurture and leverage entrepreneurship for sustainable economic development" (Acs et al., 2014, p. 477). Drawing on the NIS concept, researchers have noted the relevance of these systemic concepts for regions and sub-national actors, not least because of the scale and complexity of innovation at the level of the nation as a whole combined with considerable sub-national heterogeneity within countries (Cooke et al., 1997; Asheim et al., 2011). Because of the complexity of researching these issues at a national level, some scholars have advocated the need to explore 'regional' rather than 'national' systems of innovation (Cooke et al., 1997). Processes such as knowledge spillovers, agglomeration economies and external economies also operate differently at the level of a region (Oughton et al., 2002). Localised institutional landscapes (Gertler, 2010) and 'arrangements' also vary markedly within countries (Asheim et al., 2011; Rodriguez-Pose, 2013).

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At its most rudimentary level a "regional innovation system can be thought of as the institutional infrastructure supporting innovation within the production structure of a region" (Asheim and Coenen, 2005, p. 1177). Universities, public sector research organisations, skills development bodies, venture capitalists, regulatory bodies and so on are all key actors within a RIS (Cooke et al., 1997). According to the main economic development agency in Scotland, successful innovation is produced by "linking together ideas, technology, finance and production networks" within the RIS (Scottish Enterprise, 2013, p. 14). In other words, policy makers perceive innovation systems as the process of turning ideas into new products and services or "economically useful, knowledge" (Lundvall, 1992, p. 2).

According to one observer, a RIS has two main sub-systems: a 'knowledge generation' sub-system and a 'knowledge exploitation' sub-system (Cooke, 2004). Most empirical studies deal with the generation, rather than the diffusion, of innovations (Carlsson, 2006). Consequently, policy makers often promote 'knowledge generation' policies rather than 'knowledge exploitation' interventions. In Scotland, the Intermediate Technology Initiative (ITI) is a good example of the knowledge generation-focus of these technology policies. This was a hugely ambitious programme with a projected budget of £450 to generate novel IP in areas such as energy, life sciences and digital media (Edgar, 2009). The main aim of the ITI was to generate nascent TBFs. In the end the project was aborted, having generated little in the way of tangible outputs such as patents or new start-ups (Brown and Mason, 2012a). The programme has since become symptomatic of the 'flawed' linear approach towards research commercialisation and entrepreneurship policy within much of the UK's technology policy (House of Commons, 2013).

It is now well accepted that each RIS has its own unique entrepreneurial and inter-firm dynamics, organisational ecosystems and institutional context. A central defining feature of the Scottish innovation system (SIS) is the strong role played by the Higher Education system (Lyall, 2005, 2007; Huggins and Kitagawa, 2012). This is similar to a number of other small European countries like Denmark, Finland and Sweden who also heavily invest in higher education. Scotland outperforms its UK counterparts on a number of innovation measures, notably the proportion of UK higher education research funding, the proportion of UK graduates and citation indices (Roper et al., 2006). It also exceeds the rest of the UK in terms of the number of USOs with two Scottish universities in the top five of most successful generators of USOs in the UK (The Herald, 2013).

Scotland's innovation performance is highly dichotomous, however, with a very strong higher education sector contrasting with business innovation and entrepreneurial activity which both lag well behind the EU27 average (Coad and Reid, 2012). In fact, Scotland has a very low level of business expenditure research & development (BERD) which is currently around half (i.e. 0.56%) the level of the UK as a proportion of GDP (i.e. 1.14%) (Coad and Reid, 2012). This can be partly attributed to Scotland's status as a 'branch plant economy' and lack of domestically headquartered firms (Brown and Mason, 2012b). Moreover, the majority of Scottish SMEs have very low levels of innovative capacity (Roper et al., 2006). Similarly, the SIS has weak connections between its HE sector and its business sector which again is a feature strongly characteristic of its SME population which typically has very low levels of absorptive capacity (Harris et al., 2013).

The analytical power of the NIS concept is its ability to help shed light on the functioning of both sides of the innovation-entrepreneurship nexus which potentially helps policy makers to prescribe policy instruments at a systemic level (Wieczorek and Hekkert, 2012). According to some scholars, entrepreneurs "are essential for a well-functioning innovation system" (Hekkert et al., 2007, p. 421). This aspect is often overlooked by policy makers. Typically, policy efforts are directed towards knowledge generation aspects of these systems, neglecting the crucial role of the knowledge exploitation aspects or 'entrepreneurial ecosystem' (Dodgson et al., 2011; Mason and Brown, 2014). Analysis of the Dutch approach to systems thinking found that public policy continues to be shaped by market failures arguments rather than wider systemic factors (Woolthuis et al., 2005). Scottish technology policy displays a similar tendency to use the language of systems thinking but without necessarily being able to 'walk the walk' in terms of policy interventions (Lyall, 2007; Brown and Mason, 2012a). This is partly reflected in the strong role ascribed to supporting individual firms, especially NTBFs, within policy frameworks rather than systemic policies to address the diffusion of innovation across the RIS as a whole.

Therefore, from a policy making perspective, in some cases systemic public policy can be characterised as 'old wine in new bottles' (Freidman, 1991). While the substantive focus of policy has remained mostly unchanged the language has changed dramatically during this period. This raises important questions about the possible disconnect between 'elite' policy-makers within the EU and OECD who promulgate the concepts of 'systemic' innovation policy and its translation and implementation at regional and local levels. This resonates with recent observations highlighting the limits to policy action by innovation policy makers and suggests that bold or radical new policy initiatives need to go hand-in-hand with greater levels of institutional capacity building at a local level (Uyarra and Flanagan, 2010; Melancon and Doloreux, 2013). For this to happen, much more research needs to be directed towards looking inside the policy 'black box' (Uyarra, 2010) to better understand the ways in which policy interacts with local entrepreneurial agents.

4. Definitions, data and method

The conventional approach to the identification of 'high tech' firms is based on an industry approach, with 'high tech' industries being defined on the basis of particular attributes. This approach was pioneered in the UK by Buchart (1987). Based on the four digit level of the 1980 Standard Industrial Classification (SIC) he identified high tech industries as those which had higher than average expenditures on R&D as a proportion of sales or employed proportionately more 'qualified scientists and engineers' than other sectors. This definition has been updated by Glasson et al. (2006) in their study of high tech industry in Oxfordshire using 2003 SIC. They further argued that the definition needs to take account of the local or regional industrial structure. Accordingly, the Glasson et al. (2006) definition was modified to take account of local/regional circumstances of the Oxfordshire economy. This combination of rigour, derived by using measurable criteria, plus an element of subjectivity to take account of local circumstances, has considerable appeal. Therefore, the Glasson et al. (2006) definition was modified to include the oil and gas sector which is a powerful locus of industrial strength in Scotland. A full list of the SIC codes adopted are outlined in Table 1. The weaknesses of defining high tech firms on the basis of industry characteristics are, first, by no means is every firm in these sectors necessarily 'high-tech' and, second, it excludes high tech firms in industries that are not defined as high tech.

The study had three main components. First, quantitative analysis was undertaken on the aggregate nature of TBFs in Scotland using the industry definition outlined above. This aggregate analysis utilised the Inter Departmental Business Register (IDBR)-based Business Demography dataset held by the Office for National Statistics (ONS). The main benefit of using this dataset is

Table 1
High tech sectors by standard industrial classification (based on SIC 2003).

High-tech manufacturing activities	
11.1, 11.2	Energy
22.1, 22.3	Electronic publishing
24.4, 33.1	Life Sciences
25.24, 26.15, 26.82	Composites and other advanced materials
28.52	Precision engineering and precision components
29 (all)	Machinery and equipment not classified elsewhere
30.01, 30.02	Computer equipment and office machinery
31.1, 31.2, 31.4, 31.62	Electrical equipment
32.1, 32.2, 32.3	Electronic equipment and components
33.1, 33.2, 33.3, 33.4	Medical and surgical equipment
34.10, 34.3	Transport equipment
35.3	Aerospace and related activities
36.5	Manufacture of games and toys
High-tech service activities	
64.2	Telecommunications
72.2	Software development and consultancy
72.6	Web/internet services
72.1, 72.3, 72.4, 72.5, 72.6	Other computer
73.1	R&D (natural sciences and engineering)
74.2	Architectural and engineering activities
74.3	Technical testing and analysis
74.60/2	Security and related activities

the ability to compare Scotland with other parts of the UK. Second, using the SIC-based definition above, 76 TBFs were identified from the FAME database as being Scottish owned. Each of these firms was subjected to detailed desk research which drew on newspaper articles, websites and analysis of business databases. Third, in-depth interviews were conducted with a random sample of nineteen of these firms which helped to inform our secondary analysis of these firms with in-depth qualitative information. Finally, interviews were conducted with account managers from the regional business support agency, some of whom work intensively with the companies interviewed. As other scholars have done these were used to triangulate the findings from the company interviews (Fischer and Reuber, 2003).

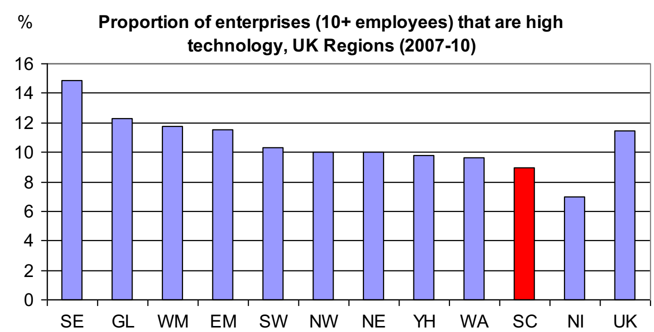

Fig. 2. Proportion of enterprises that are in high technology sectors, by UK region. *Source*: ONS Business Structure Database.

5. An overview of technology based firms in Scotland

Applying the SIC-based definition outlined above to the IDBR business demography dataset for the 2007–10 period, we identified 7462 TBFs in Scotland. The vast majority were micro-firms employing fewer than 10 employees (86%). In fact only 1021 TBFs in Scotland (14%) have more than 10 employees, of which just 278 (27%) are Scottish owned. As shown in Fig. 2, Scotland performs poorly in terms of its proportion of firms that are TBFs (9%) compared to the UK average (11.5%) and even worse against the OECD average of 15% (OECD, 2000). While it might be expected that Greater London and South East England would have much higher proportions of enterprises that are high tech, Scotland's ranking below regions in the English ‘north’ is surprising and difficult to explain. TBFs are also geographically concentrated with a high proportion found in Aberdeen and the surrounding Grampian area which is a major centre for offshore oil and gas production. Indeed, our analysis of the FAME database found that 13% of all TBFs in Scotland are in the oil and gas industry and a further 21% of firms in other sectors derive all or most of their sales from this sector.

The standard OECD definition of high growth firms (HGFs) only considers firms with more than 10 employees. Under this definition firms achieving this benchmark are ‘*enterprises with average annualised growth in employees or turnover greater than 20% per annum, over a three year period, and with more than 10 employees in the beginning of the observation period*’ (OECD, 2008). Of the population of TBFs with more than 10 employees (i.e. 1021), only 12.2% of Scotland's HGFs (or 188) fall into the high growth category, a lower proportion than most UK regions (Fig. 3). Again, the south east of England is the strongest performer in terms of high growth TBFs. Scotland's poor showing corresponds with other northern UK regions and is consistent with the typical north–south divide in terms of innovation and business performance (Keeble, 1997; Huggins and Kitagawa, 2012).

This initial aggregate analysis of Scotland's high tech sector immediately challenges many of the ‘stylised facts’ about the sector and also raises questions about the outcomes that have been achieved through over 30 years of targeted policy intervention designed to promote these firms. The population of TBFs is relatively small and the vast majority are small micro firms with fewer than 10 employees. Indeed, our analysis also noted that Scottish high growth TBFs tend to be younger and smaller than the overall population of Scottish HGFs. Moreover, in comparison to other UK regions Scotland produces fewer high growth technology firms. Specifically, there are only a handful of companies in Scotland that have managed to achieve a significant size to become companies of scale with a turnover over £100million. This lack of so-called high-tech ‘gorillas’ within the wider UK economy has been noted by others (Owen, 2004).

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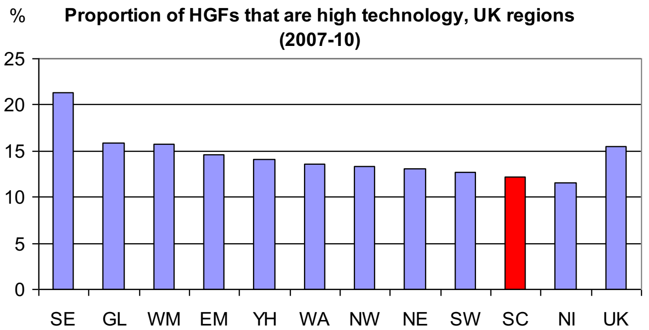

Fig. 3. Proportion of high growth firms that are in high technology sectors, by UK region.
Source: ONS Business Structure Database.

6. The nature technology based firms in Scotland

6.1. Age and ownership

The 19 Scottish owned companies that were interviewed (around 7% of the population of Scottish owned TBFs with 10 or more employees) exhibit considerable diversity in terms of age and ownership structures. In terms of age, eight were less than 10 years old when interviewed with a further seven founded in the 1990s. Several were founded in the 1960, 1970s and 1980s. Two originated in the 19th century. Some have undergone significant ownership changes including one that has undergone a management buyout (MBO) and another that was an employee-buy out. Another firm was created through a management buyout of two formerly Scottish owned businesses that had been acquired by a French company. The effect of this MBO was therefore to return two former Scottish companies to Scottish ownership and control. It has subsequently been acquired. Many of the TBFs interviewed have had quite turbulent origins and convoluted initial growth trajectories which involved company restructuring and ownership changes which belies the typical portrayal of these firms as de novo start-ups.

6.2. Entrepreneurial antecedents and founding circumstances

The companies interviewed had diverse founding circumstances. On the whole, universities were not found to be a major incubator of TBFs. Only three of the firms originated from universities and none had retained their original ties to the higher education sector. Many of the entrepreneurs interviewed started their new business in the same industry in which they had experience as an employee. Indeed, it was their knowledge of the industry which enabled them to see the opportunity that they went on to exploit through their own business. The biggest category of founding entrepreneurs that were interviewed (eight) had previously worked in the same industry in which they set up their business. Often the decision to start their own business was precipitated by changes in the company for whom the entrepreneurs previously worked. The need for some kind of displacement to precipitate entrepreneurial action is well established in the entrepreneurship literature (Shapero and Sokol, 1982).

Clearly, by establishing a venture in an area that they had previously worked the entrepreneur(s) had pre-existing knowledge of the market they were entering. For example, two firms were founded by serial entrepreneurs looking for opportunities in the same industry as their previous ventures. Quite often this industry knowledge meant that the entrepreneur(s) knew of an existing gap in the market for a product or service which, on the face of it, would enhance the capabilities of a new business. They also benefited from having contacts and networks which helped develop potential customers at an early stage of the firm's lifespan. The most important source of entrepreneurs was large existing corporate organisations in Scotland (especially for the oil and gas industry) and inward investors (especially for electronics/software firms). These working environments provide entrepreneurs the experience of running large scale internal operations for their past employers which gave them the confidence and skills to grow an independent business.

6.3. Activities

The companies undertake a variety of activities, covering both manufacturing and service activities. Seven firms were in the manufacturing sector: health/medical products, engineering equipment, telecoms hardware, semi-conductor chips and battery systems sectors. Typically these firms also undertake other activities, notably research and development (R&D), software development and distribution. Two other companies undertake manufacturing-related activities – refurbishing machinery and customising, repairing and refurbishing values and gas turbines. The remaining firms were service-related. The biggest single category comprised software-related companies (n 4). Two firms are life sciences services providers. Three other firms also provide services: internet dating, IT services, and architectural and design services. There was only one example of a ‘soft’ company which was entirely reliant upon contract R&D for its existence (Probert et al., 2013). The firms deliver their products and services in a variety of ways, including customised solutions, one-off and small batch production, subcontracting work and subscription services. Three firms emphasised the importance of their unique business model which is increasingly viewed as a key source of competitive advantage (Teece, 2010). For example, one of the companies sells billing software to US hospitals and has business model based around multiple year contracts (five years on average).

6.4. Growth patterns

As the literature suggests (Garnsey et al., 2006; Mohr and Garnsey, 2011), the growth process of these TBFs was highly discontinuous and non-linear. The majority (11 or 60%) had exhibited steady, and in some cases extremely rapid growth in recent years. Most of the remainder (n 7) reported growth until the onset of the economic downturn in 2008. Three of these companies reported that growth had subsequently resumed but another three reported that sales had not recovered owing to the fragility of the economic recovery. Growth was largely organic for most of these TBFs. However, acquisition was important for a sizeable minority: five firms had made acquisitions but even in these cases most of their growth was organically driven.

Many of the TBFs encountered key ‘growth triggers’ or growth catalysts which have a major influence on a firm's future growth potential (Brown and Mawson, 2013). It appears that trigger points within TBFs (e.g. new product development, injections of venture capital, new market entry) may occur even more rapidly and repeatedly than in firms in more traditional industries. Regulatory change – which can also represent a growth trigger – is also more common in areas of emerging technology than in more established sectors. How firms manage to exploit these strategic growth catalysts often heavily shapes their future growth trajectories.

6.5. Financing

The companies have been financed in a variety of ways. Five firms have been entirely self-funded. In most cases this has either been because bank finance was not available, or the terms and conditions of debt finance was unacceptable, or an unwillingness to dilute ownership to raise venture capital. Two firms are currently listed on AIM. Another was listed on AIM in 2005 but went into administration in 2009 and was bought out by its biggest shareholder and lender. Two firms had raised finance to go through a management buyout. In one case this was funded by private equity. In the other case the change in ownership was to an employee-owned company. Six firms raised venture capital – four from VC firms and two from angel groups. Finally, four firms have been financed by bank debt. The majority of firms (74%) reported obtaining various forms of public sector funding including R&D/technology and capital investment grants which is indicative of the high levels of public support these firms receive. The fact that only a minority of firms had been venture capital backed is noteworthy, as this is how technology firms are typically portrayed as being financed (Lerner, 2010).

6.6. Technological strategy

There is a stereotype of a technology firm as being what Bhidé (2010) termed 'a science project', with highly qualified staff in white coats, strong links with universities, proprietary technology, protected intellectual property and leading edge products. The reality is rather different. While some firms match this stereotype, the vast majority do not fit the conventional characteristics of a technology business in terms of a strong R&D focus, graduate workforce, and patents. There are several reasons for this.

First, because of the way some of these firms are structured, for example, being embedded in project teams, not every firm has an R&D department or formalised R&D activities. Certainly all of the firms that were interviewed during the study are trading on the basis of their technological knowledge. In some cases this knowledge is internally developed from internal R&D. But in other cases it simply derives from the deep domain knowledge of the management team. Many firms attribute their expertise to their close working with customers or end-users (von Hippel, 2009). Second, just over one-third of the interviewed firms have over 75% of graduates amongst their workforce. At the other end of the spectrum, around one-quarter had fewer than 25% of graduates in their workforce. In all cases these were manufacturing and manufacturing-related businesses. Third, only two firms have significant research links with Scottish universities and another firm has a project with a local university. One company – which claimed to be a university spin-out – said that it now has very few links with that university. Three other firms had university links in the past but these have now ceased. Many of the firms were dismissive of universities as a source of knowledge. One of these firms was critical of universities for "operating on a different time scale and slow to react." None of the respondents mentioned universities as an important source of innovation or human capital.

Finally, most – 16 out of 19 – claimed their technology is proprietary. In some cases this technology is embodied in products and software. In other cases it contributes to process innovation. In yet other cases it is used to develop customised 'solutions' for customers. However, only a quarter of the firms (n 5) had patent protection. Some of these firms take the view that patent protection is ineffective ("it can be blown away"), is at risk to 'patent trawls' and too expensive for small firms to defend against infringement. Others simply say that patents are too expensive, particularly if there is a need to register them in multiple jurisdictions.

6.7. Customers and markets

Most of the interviewed firms are selling to other businesses. Just two firms have significant consumer sales. However, there is considerable diversity in terms of the markets served. The biggest concentration is in the medical-health sector, with five firms selling into this market. Three of these firms have US hospitals as their major customers. The importance of the North Sea oil and gas sector as a source of 'market pull' was also noticeable, confirming the desk research. Four companies sell into this sector. This can, in turn, open up opportunities to work with the same customers in other energy markets worldwide. For example, one company leveraged the oil majors that it has served in the North Sea to work with them in other energy regions around the world. This company now has 15 subsidiary companies, and operates in 234 locations across every continent. An IT company has also 'travelled' with its North Sea oil and gas customers into export markets and is doing the same in airport operation systems as most airport operators are now international. This type of 'piggy-backing' or intermediated internationalisation (Acs and Terjesen, 2013) is an important mechanism for technology firms to internationalise. However, it typically requires the presence of global customers in the region. As we note in the next section, electronics companies felt themselves disadvantaged by the absence of large UK-based electronics companies.

The sample of technology firms is highly international in terms of their markets. Two-thirds derived half or more of their sales from exports while one-third derived in excess of 90%. This includes both small Scottish based companies as well as the larger companies with significant physical presence in international markets. For some of the more growth-oriented TBFs, acquisition had been an important overseas market entry method.

6.8. Barriers to growth

As other work on NTBFs has found (e.g. Tether, 1997), not all the firms interviewed had an insatiable appetite to grow, with several seeking to be niche-based players. Although perhaps unsurprising, this does undermine the dominant view of policy makers that firms will become bigger if barriers to growth can be surmounted (Autio, 1997). Indeed, many of the TBFs interviewed had deliberately sought to grow to a particular size which was manageable for the current management team. Of course, some of the firms in the sample were very ambitious and growth-oriented but an equal number of TBFs wanted to grow much more slowly and a few felt they had hit a 'growth plateau'. For some, achieving a certain size was seen as the opportune moment to sell-out. The sell-out mentality seemed particularly prevalent in some of the smaller, less established firms. This may reflect uncertainty surrounding future funding opportunities. Indeed, many of the TBFs were established with the explicit intention and desire to sell-out once they had reached a certain size. Consequently, quite a number of TBFs are acquired by larger corporate entities.

There were a variety of company-specific factors which were cited as barriers hindering growth. The main constraint related to the wider environment was recruitment difficulties, cited by one-third of companies. Just under one-third highlighted access to further finance, especially debt, as a key constraint. These companies were predominantly small manufacturers. More generally, there appears to be a particular problem for the electronics hardware companies that were interviewed which arises from their distance from the US and Far East where most of their customers are based. The absence of a major national company such as Siemens or Phillips with the market power to commercialise new technologies and act as a 'technology champion' coupled with a lack of government support for the electronics sector were cited as key growth constraints. Two companies also reported that they were disadvantaged by their small size in bidding for government contracts which prevented them from benefiting from public procurement.

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7. Discussion

The findings from this study show that the economic significance of TBFs is arguably not as great as commonly assumed. Indeed, the small scale of most firms and lack of growth-oriented, companies of scale calls in question the degree of support targeted towards these firms compared to the majority of SMEs. While the research was conducted in one small UK region, the empirical findings have resonance for other similar peripheral regional economies in advanced industrial economies such as Atlantic Canada where similarly weak entrepreneurship ecosystems exist (Melancon and Doloreux, 2013). Moreover, the fact that the proportion of high-tech SMEs is broadly similar within most advanced industrial economies suggests that this critique has relevance for the majority of OECD economies (OECD, 2000).

The vast majority of TBFs are, in reality, small micro firms and the majority of larger ones are foreign-owned. Only a few have grown rapidly or have achieved significant scale and remained Scottish owned. TBFs are a much smaller cohort and less growth oriented that policy makers typically imagine (Tether, 1997). While these firms do play an important role within economies we concur with others who question the 'special' status they have been conferred within public policy (Tether, 2000; Brannback et al., 2010). This raises important questions about the level of policy prioritisation that these firms receive. While the high-tech 'fantasies' (Massey et al., 1992) or growth 'myopia' (Autio, 1997) associated with high-tech SMEs continues to transfix policy makers (World Economic Forum, 2011), on this evidence the anticipated economic benefits from this cohort remain largely illusory. The corollary, of course, is the lack of emphasis on raising the innovative capabilities within the population of SMEs as a whole which continues to be a crucial oversight by policy makers (Hoffman et al., 1998; Toedtling et al., 2009; Harris et al., 2013).

There also appears to be a strong mismatch between the stylised facts engrained in technology policy and the reality of how these firms operate (Table 2). The empirical evidence presented here suggests that technology firms are actually quite different to how policy makers perceive them. TBFs have some common characteristics which are not immediately associated with this cohort of firms. Typically, these firms are well-established. Some are MBOs rather than de novo starts. In the main they are corporate spin-offs rather than university spin-outs. Most do not exhibit the features expected of science-based firms; they do not undertake large amounts of in-house R&D; most do not have protected IP; only a small minority are VC-backed; most derive their main competitive advantages (and sources of innovation) from relationships with end-users and customers and many are not growth-oriented.

The diversity of the technology sector – which clearly emerges in this study – also creates eligibility issues, with some companies excluded from support because of a particular view of what a TBF should do. A further reason for challenging the technology focus is that many of the support needs of TBFs are similar to those of growing firms in general: for example, lack of sales skills, inability to recruit and retain human capital, lack of strategic managerial skills, and a lack international experience within SMEs. In other words, general SME support is required for these firms rather than purely offering R&D or innovation support.

Recently scholars have found that 'open' innovation is increasingly utilised by firms as strategy for assembling their technological competences (van de Vrande et al., 2009). Smaller companies in particular "can gain a lot by open innovation as both their resources and market reach are limited" (Huizingh, 2011, p. 5). Similarly this empirical evidence suggests TBFs seem no different from other SMEs in this respect. Many of the TBFs interviewed stressed the importance of links to customers as a key source of their innovation processes (Luthje et al., 2005). The clear lesson from this is that 'technology policy' needs to reduce its emphasis on 'technology push' support and become more outwardly oriented or 'market driven' by improving the sales and market orientation of these firms, especially in terms of their ability to link with customers and end-users (Luthje et al., 2005; von Hippel, 2009; NESTA, 2010).

A critical aspect of this technology push approach is the perceived role of universities as a key driver within a RIS. As shown here and elsewhere very few university spin-offs become high growth firms (Brown et al., 2014). The importance of universities as a source of knowledge for TBFs has also been questioned. Universities do not even emerge as a significant source of human capital. The dominant role that universities have been accorded within technology policy therefore needs to be reconsidered (Harrison and Leitch, 2010). A much more likely source of rapidly growing firms is large, existing incumbent firms which also serve as major source of technological innovation within economies (Bergek et al., 2013). Technology policy should therefore be redirected to reflect the powerful role played by existing large scale businesses – both as a source of innovation and new venture formation – within innovation systems (Mayer, 2013).

Another key finding from our research is the importance of the acquisition of TBFs (Oakey, 2013). Indeed, during the study a number of indigenous TBFs were acquired, often while still relatively small. While the consequences of this process were not examined it is important to note that acquisition may have significant consequences for the firms acquired. Positive outcomes include new investment and access to the distribution channels of the acquiring company which will underpin growth. The 'recycling' of entrepreneurs and capital gains may be further benefits (Mason and Harrison, 2006). However, negative outcomes are just as likely, albeit often taking longer to emerge, with the acquired company being absorbed by the acquirer raising the possibility that its IP and key management positions will be removed from the acquired company. Meanwhile the benefits that might accrue from 'entrepreneurial recycling' will depend on the size of the company when it is acquired as this determines the amount of wealth that the entrepreneurs and other key management receive, and the experience that they have accrued. Early exits are likely to restrict both the amount of wealth and learning generated, limiting the extent of entrepreneurial recycling.

The impact of foreign acquisitions often focuses on the impact of high profile cases such as the recent takeover of Nokia by Microsoft. The downsizing of Nokia in Finland – resulting in the loss of over a 1000 jobs and the closure of a R&D centre in Oulu – is testament to the visible and controversial nature of these acquisitions (Crouch, 2014). However, there is a growing trend of larger technology companies acquiring smaller NTBFs (Granstrand and Sjolander, 1990). The impact of these smaller acquisitions is more difficult to discern. According to some, high levels of acquisition of technology companies may suggest that the economy is not reaping the full benefits of its inventive activity (House of Commons, 2013). Policy makers need to know more about the consequences of this acquisition process and potentially devise policy responses to embed TBFs to mitigate the negative consequences of overseas acquisition (Hinton and Hamilton, 2013).

What also became apparent during the study was the importance of non-organic growth for TBFs (Mohr and Garnsey, 2011; Oakey, 2013). Many of these firms had grown by acquiring other companies, including many SMEs who use this process to obtain sources of new technology (Hussinger, 2010). This non-organic approach is often part of a firm's 'buy to build' growth strategy (Lockett et al., 2011). More research is needed to explore the growth 'mode' within these firms (McKelvie and Wiklund, 2010) and how policy makers can potentially maximise the benefits for

Table 2
The 'mismatch' between high-tech firms and current technology policy.

Aims of technology policy	*Characteristics of TBFs*
The bulk of public policy expenditure is targeted towards new ventures at the beginning of their lifespan.	Most are not de novo start-ups, many are quite well-established businesses and some arise from MBOs/MBIs
The commercialisation of publicly funded research in universities and public research centres is seen as the central mechanism for creating TBFs	Most TBFs are spin-offs from existing corporations, not university spin-offs
Most interventions and business incubators are strongly targeted at science-based industries (pharma, microelectronics etc.). Sectors which generate substantial amounts of TBFs are often overlooked (e.g. oil and gas in Scotland)	TBFs emerge from a wide variety of sectors and industries.
Policy aims to promote more technology and mostly focuses on expenditure on developing physical capital rather than developing human or 'entrepreneurial capital'	The success of these firms is heavily driven by opportunity driven nature of the 'entrepreneurs' rather than unique technology or IP which is embodied within their products or services
Capital grants, tax incentives, human capital subsidies to promote intramural R&D	Most have no R&D department or functions and few conduct formal R&D
Most innovation agencies encourage linkages between higher education and SMEs. Few state programmes (if any) foster linkages to potential customers or end-users.	Most rely on 'open' sources of innovation often from customers, end-users and suppliers etc.
Business mentoring heavily stresses the need for formally protected IP. Subsidies for patent protection are sometimes offered to TBFs	The minority of TBFS have protected IP
Business development agencies promote risk finance as the main source of finance for NTBFs.	A small minority are venture capital-backed. The main source of funding is traditional debt funding.
Most policy assistance takes little account of the 'temporal' nature of the growth process. Interventions are generally made early phase in the lifespan of these firms.	Many TBFs grow in a discontinuous and lumpy fashion and many take time to achieve any kind of growth. Growth triggers are important for many of these firms often a considerable time after a firm's birth.
Policy assumes most firms have the desire and ability to become companies of scale.	Many seek to be small niche-based players or exit via a trade sale rather than upscale into larger scale businesses.

local firms who grow in this manner. At present, public policy does not help assist firms with non-organic growth. Potentially there could be a role for economic development agencies to support firms with their M&A strategies, especially as SMEs increasingly use this as part of their 'open' innovation strategies.

8. Policy implications

We now turn to an examination of specific policy areas which need to be developed to address some of the current problems within technology policy aimed at TBFs. First, given the lack of traditional science-based R&D within the successful TBFs interviewed there is an urgent need to broaden out the types of innovation support granted to such firms. This is in line with others who have found that mistargeting of policy has resulted in traditional SMEs which undertake less formal innovation processes being largely overlooked within innovation policies (Kaufmann and Toedtling, 2002). The nature of support also needs to be shifted away from an exclusive focus on transactional R&D support in the form of grants or tax incentives. There remains a lack of innovation support to help improve links between SMEs and their customers, end-users, suppliers etc. Specifically, there seems a lack of support facilitating the 'connective capacity' of firms – that is, the ability of firms to connect with significant external sources of innovation capacity. There is a strong argument that innovation support should specifically foster links between TBFs and their potential end-users, especially given the increasing importance of these 'open' sources of innovation for SMEs (van de Vrande et al., 2009; Huizingh, 2011).

Second, governments fail to use their huge procurement budgets to support indigenous companies (Aschhoff and Sofka, 2009; Miles and Rigby, 2013). It therefore seems clear that policy-makers are failing to use one of their most effective business support instruments they have available as a demanding customer for goods and services (Miles and Rigby, 2013). Some respondents specifically criticised government tendering for disadvantaging smaller companies. This suggests that the US practice of allocating a certain proportion of public sector spending to small firms should be considered. Indeed, the adoption of this kind of policy framework is becoming evident in some other countries, with Finland recently producing a 'demand-driven' innovation policy (Miles and Rigby, 2013). Likewise, steps are also being taken in Canada to leverage the benefits of public procurement for smaller firms (Action Canada, 2012).

Third, the study raises important questions around which sectors should receive business support. Some scholars make the point that policy makers focus on high tech firms "as a priority" when other sectors might pose better opportunities (Buss, 2002, p. 18). At present, the key sectors outlined in the Scottish Government's Economic Strategy are predominantly technology-focused (Scottish Government, 2011). Again, this focus on high tech sectors is a recurrent trend that is deeply engrained in the majority of cluster policies adopted in OECD economies (Hospers et al., 2008). Our work suggests too much emphasis within technology entrepreneurship programmes, both directly and indirectly, is attached to supporting a narrow range of high tech sectors. Certainly the considerable support that has gone into areas such as the life sciences sector (which one respondent identified as 'fixation' of policy makers) is not justified by the findings of this study.

In contrast, high-tech engineering suppliers to the oil and gas industry have been identified as a significant source of high growth TBFs during this research. Despite being a key engine of growth within the Scottish economy, arguably the spillover effects of the oil and gas sector to the rest of the economy does not get the full recognition from it merits from policy makers. Policies which attempt to "push water uphill" seem likely to be unsuccessful and wasteful of resources. Hence, in geographically remote resource-based economies, such as Scotland, Scandinavia, New Zealand and peripheral regions of North America, perhaps a better focus would be to identify the sectors which have stronger indigenous capabilities within existing SMEs. For example, in Finland, steps are being made to broaden the investment portfolio of SITRA, the state-funded investment vehicle, to include sustainable forestry firms (SITRA, 2012). This is in line with the EU's Smart Specialisation policy framework which is now increasingly informing regional innovation policies and SME support across the EU (European Commission, 2013).

Finally, policy makers have tended to focus the vast majority of innovation support towards new starts and SMEs (Tether, 2000; OECD, 2010b; Brown et al., 2014). Ensuring that existing companies, and not just new start-ups, are eligible and targeted is important. This chimes with the increase in prominence now attached towards the concept of 'economic gardening' first pioneered in the US sate of Colorado. This approach to economic development focuses on leveraging the stock of growth-oriented SMEs within the local economy rather than focusing on new starts or external investment (SBA, 2006). For example, management buyouts of existing companies, or parts of existing companies, are important sources of new fast growing businesses (Wright et al., 2001; Mason and Brown, 2010). Indeed, one firm interviewed claimed that "there is undoubtedly imprisoned value in large businesses". However, unlocking this value does not appear to be a priority for policy-makers.

9. Conclusions

This paper challenges some of the 'stylised facts' surrounding high-tech firms. This critique aims to provide a timely corrective to misconceived policy approaches towards technology entrepreneurship. The empirical evidence presented suggests that technology firms are actually quite different to the perception that policy makers have of them and, as a consequence, many public policies are ill-equipped to support them. These firms are not the powerful driver of growth imagined by policy makers and are far-removed from the Silicon Valley stereotype commonly portrayed. Although focused on Scotland, this conclusion is highly relevant for many other countries, especially those following 'mission-oriented' technology policies which heavily focus on generating NTBFs. By closely examining the nature of entrepreneurship, some of the myths attached to these firms have been exposed as high-tech 'fantasies' (Massey et al., 1992). This has resulted in too strong a focus on high-tech SMEs and not enough attention on improving the innovation processes across all SMEs. Developing a deep understanding of the complex reasons for this kind of misdiagnosis within technology policy is very important if policy failures are to be better understood and averted (Markusen, 2000).

These findings suggest that the specificities of technology policy require substantial recalibration (Cox and Rigby, 2013; Mason and Brown, 2013). Advancing entrepreneurial behaviour and honing a firm's dynamic capabilities should be seen as an integral part of developing a firm's technology strategy (Teece, 2007). In order to develop systemic capabilities within innovation systems (Iammarino et al., 2012), policy makers must, as a matter of priority, develop a different set of policies and interventions to the linear transactional forms of assistance which continue to dominate many technology policies. This policy re-configuration will probably pose greater challenges for some countries, especially economies like the UK and US, which are deeply aligned with market-failure driven policy frameworks. It follows from this that innovation and entrepreneurship scholars also need to develop a deeper understanding of the innovation-entrepreneurship nexus (Radosevic and Yoruk, 2013) and the specificities of technology entrepreneurship (Beckman et al., 2012) if they are to provide more meaningful advice to policy-makers. Exploring the systemic factors mediating the process of entrepreneurship seems a useful pathway towards this end (Acs et al., 2014).

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