Firms in Scottish High Technology Clusters:
software, life sciences, microelectronics, optoelectronics and digital media
– preliminary evidence and analysis on firm size, growth and optimality

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Abstract
This paper reports on: (a) new primary source evidence on; and (b) statistical and econometric analysis of high technology clusters in Scotland. It focuses on the following sectors: software, life sciences, microelectronics, optoelectronics, and digital media. Evidence on a postal and e-mailed questionnaire is presented and discussed under the headings of: performance, resources, collaboration & cooperation, embeddedness, and innovation. The sampled firms are characterised as being small (*viz.* micro-firms and SMEs), knowledge intensive (largely graduate staff), research intensive (mean spend on R&D GBP 842k), and internationalised (mainly selling to markets beyond Europe).

Preliminary statistical evidence is presented on Gibrat's Law (independence of growth and size) and the Schumpeterian Hypothesis (scale economies in R&D). Estimates suggest a short-run equilibrium size of just 100 employees, but a long-run equilibrium size of 1000 employees. Further, to achieve the Schumpeterian effect (of marked scale economies in R&D), estimates suggest that firms have to grow to very much larger sizes of beyond 3,000 employees. We argue that the principal way of achieving the latter scale may need to be by takeovers and mergers, rather than by internally driven growth.

Key words: High technology, Scottish firms, Gibrat's Law, the Schumpeterian Hypothesis
JEL codes: O18, O31, O34, O38
Revised version: 28.10.08

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Firms in Scottish High Technology Clusters: software, life sciences, microelectronics, optoelectronics and digital media – preliminary evidence and analysis on firm size, growth and optimality

1. Introduction

This paper presents preliminary evidence and analysis on Scottish high-technology firms over the period 2003-04 (cf. Scottish Executive, 2004). The data reported upon consist of new primary source evidence, obtained from over eight hundred firms across five sectors, under the headings of: performance, resources, collaboration & cooperation, embeddedness, and innovation. The clusters considered were in the following technologies: software (cf. Scottish Enterprise, 2002), life-sciences (cf. Scottish Enterprise, 2002), microelectronics, optoelectronics (cf. Scottish Enterprise, 2005) and digital media.

The principal findings are: (a) that these Scottish high technology firms are small, research and knowledge intensive, and internationalised; (b) that they have high but falling growth rates, with an implied short run equilibrium size of about one hundred employees; (c) that their long-run equilibrium size, taking account of future investments and organisational innovation, may be as high as one thousand employees; and (d) that, nevertheless, they would need to be at least three times larger to enjoy the benefits of industrial-style scale economies of R&D. Concerning the latter, it is argued that growth to this scale (*viz.* of beyond three thousand employees) is unlikely to be possible by internally generated growth, and that therefore it may need to occur, if at all, by a process of takeovers and/or mergers.

These results are developed in this paper in the following order: high technology clusters characteristics; research methodology, including questionnaire design; key results, as provided by the questionnaire returns; and finally statistical and econometric evidence, focusing on tests of Gibrat's Law (see Gibrat, 1931; Sutton, 1997) and the Schumpeterian Hypothesis (see Acs & Audretsch, 1991; Kohn & Scott, 1982), using cross section evidence, with a dynamic component to it. A concluding section reviews the whole paper and remarks upon key results.

2. A Brief Review of Theory, Evidence, Policy, and the Scottish Context

The meanings attached to the term 'high technology' are diverse. Definitive analyses by the likes of Kadoma (1991) and Markusen et al (1986) suggest that the following attributes are characteristic of high technology activity: a high ratio (greater than unity) of R&D expenditure to capital investment; the creation of new possibilities through the 'collision' of existing technologies (e.g. classical optics, laser technology and microprocessors for control in the field of optoelectronics); a short product life cycle, and a rapid development cycle; diversity in technological endeavour; and a mediating of supply side technological possibilities with demand side driven technological needs or desires. The latter relate to both the demands of the ultimate consumer, and to demands generated by business to business relationships.

Whilst there is no presumption of the economic superiority of high technology activity over primary (e.g. agriculture, mining) and secondary (e.g. heavy and light manufacturing) economic activity, the fact is that high technology has been a focus of economic interest, in theory, practice and policy. This is because of its capacity to drive growth, employment and technological change. These, in turn, improve competitiveness and help the economy to meet key policy objectives, like stimulating deprived regions and exploiting the knowledge base created by the higher and further technology education sector. Because Scotland itself has a strong history of innovation, and a good educational system, yet has been subject to recurrent problems of poor competitiveness and regional depression, it is natural that the high technology industries should be viewed as a focus of economic and educational policy (e.g. *A Smart Successful Scotland: Ambitions for the Enterprise Networks*, Scottish Enterprise, 2001).

Whether high technology best flourishes in a particular type of milieu has been a source of considerable debate (e.g. Agdabot, 1986; Maillat, 1995; Camagni, 1995). This clash of ideas has suggested that the locus of innovation per se may be less important than that the process of innovation itself should proceed. Nevertheless, 'locus' or 'place' of innovation has been a persistent theme, down the decades, and indeed the centuries, right from Adam Smith's (1776) observations on the concentration of naileries in Kirkcaldy, on through Alfred Marshall's (1890) 'industrial districts', up to Porter's (1998) analysis of what he calls 'clusters and the new economics of competition'. These approaches have all had a bearing on Scottish policy (e.g. Scottish Enterprise, 1998).

Whilst clusters themselves need not be associated with a highly innovative milieu – which they need not be, as economies of agglomeration alone may be sufficient to foster clusters, there is a common presumption that this is the case. Indeed, this has often been so of cluster policy in Scotland. Dating back, for example, to the 1970s, the Scottish Development Agency (SDA) focused attention on developing electronic clusters (in the so-called Silicon Glen, see Baggot, 1985) to some considerable effect. Policy initiatives have focused on matters like technological upgrade, capital inflows and employment creation (McCann, 1997). Scottish Enterprise, the successor institution to the SDA, has thought, more generally, of clustering as being a process of economic development (see Bram, 2000). As such, it does not focus too heavily on more traditional views which focus on ‘place’ or ‘locus’ (e.g. as in Marshall’s industrial districts).

Scottish policy, the background to the research reported here, has been most heavily influenced by Porter’s (1998) approach, as developed by the likes of Bergman and Feser (1999) and Lagendijk (1999). The latter individuals focus on community as the source of dynamics for a cluster. Thus it is built on consultation and collaboration with government agencies, industry and social stakeholders. Scottish Enterprise developed ‘cluster teams’ to implement a policy of this sort, adopting a so-called ‘market opportunities’ approach, which moved away from an earlier emphasis on low cost and high labour intensity, to one more focused on high productivity, greater innovation and enhanced competitiveness. The research of Porter’s ‘Monitor Group’ of 1993 was able to identify eight clear clusters in Scotland. These were advanced for policy attention and support, because they were thought to have good long-run potential for growth. These clusters were: biotechnology, optoelectronics, semiconductors and creative industries, in the ‘new’ economy; and forestry, food and drink, energy and tourism, in the ‘old’ economy. In fact, these ‘old’ and ‘new’ distinctions can be misleading, as all the latter clusters themselves are often subject to considerable innovation.

To summarise, concepts of high technology and clustering are well defined and well understood (cf. Surinach, J., R. Morena, and E. Vaya (eds.), 2007). Further, they have been taken up, and extensively used, in the creation of modern industrial policy in Scotland. That has led to the development of explicit policies for specific clusters; and the purpose of the research reported upon here is to look at the performance and innovation of these clusters.

3. Research Methodology

The empirical analysis of this paper is based on new primary source data. The data gathered were obtained (in 2003-04) from high technology firms in Scotland, across five sectors: optoelectronics, microelectronics, digital media, life sciences and software. These sectors are the cornerstone of Scottish high technology policy (Scottish Enterprise, 2002a, *Partners in Development*), and indeed were selected by us for this reason. Of these, software was not included in the DTI's cluster mapping exercise, nor in Scottish Enterprise's earliest cluster initiatives, whilst the others were. However, it is a large and thriving sector, dealt with under other SE initiatives. For example, in the *Scottish Software Game Plan* of 2003, its synergies with other major knowledge based industries were specifically noted as being crucial to what was described as 'the national economic ecosystem'. This is important, as software is the largest high-technology sector in Scotland, being host, at the time of the study, to world leading companies, like IBM, NCR, Hewlett-Packard, Cisco, Sun and Oracle.

The enquiry was conducted using a questionnaire which examined: performance; resources; collaboration and cooperation; embeddedness; and innovation. The outline of the questionnaire is given in Table 1 and the full questionnaire, with statistics of responses, is given in the Appendix to this paper. General discussion of these results, and the formulation and testing of hypotheses that are predicated on these results are developed below. Here, we focus on methodology.

[Table 1 near here]

The instrument (questionnaire) was piloted in August 2003, and the postal questionnaire was implemented between October 2003 and January 2004. The database of all firms contacted was constructed separately for each sector (see Table 2). Then firms were identified as being specifically high technology enterprises, using the SIC codes defined as relating to high technology by Butchar (1987), for the UK, and by Thompson (1987) for the USA. For sectors which were not SIC-based, Department of Trade and Industry sources were used (see DTI, 2000, 2001) to extract the high-technology firms.

[Table 2 near here]

In making a comparisons between the Scottish population distribution of high technology firms, and the sampled ones, for these five high technology sectors of Table 2, reference was made to the Scottish Executive's *National Statistics Publication* (see *Scottish Economic Statistics*, 2004, 2005), where data for the relevant year, namely 2003, were available. A χ^2 test indicated that the sectoral composition of

Table 1: Outline of Questionnaire

A. **Performance**
Size, new products, IPO, patenting

B. **Resources**
Staff complement, skills, training, R&D, time to market

C. **Collaboration and Cooperation**
Location, frequency of contact, purpose served

D. **Embeddedness**
Local recruitment, staff mobility, founder's experience, sales and purchases (by territory)

E. **Innovation**
Innovation spend, information for innovation, objectives of innovation, impediments to innovation

Table 2: Sources and Composition of Population and Sample

Sector Sources	***Population***	***Sample***
1. Software		
Software IS	186	186
Lanarkshire Software	52	19
Rampart Scotland	80	25
2. Life Science		
Biotech Scotland	440	150
3. Microelectronics		
Scottish Microelectronics	203	187
4. Optoelectronics		
Scottish Optoelectronics Association	90	80
5. Digital Media		
Interactive Tayside for Digital Media	200	189
TOTALS	**1251**	**836**

our sample (see Table 2) did not differ significantly from that found in the Scottish population of firms [$\chi^2(4) = 0.345 < 9.49$, for $\alpha = 0.05$].

Finally, as regards the underpinning of the research question addressed in the questionnaire (see Appendix), an important reference point was the OECD's Oslo Manual (see OECD, 1996, 1997) so far as guidelines are concerned, and the 'house style' of the (then) Centre for Business Research (CBR) of the University of Cambridge. In its focus on new and improved products, an important intellectual influence is Schmookler (1996). That aside, the design, content and format of the questionnaire are novel, and aimed to be both well found in the literature and of a design that would facilitate statistical and econometric testing (e.g. of Gibrat's Law, the Schumpeterian Hypothesis, and the Innovation-Performance relationship).

4. Key Results

Whilst the primary purpose of the questionnaire was to generate data suitable for econometric and statistical analysis, the raw and semi-processed data from the questionnaire provides evidence which is, we believe, a fascinating 'snapshot' (and, in some cases, a sequence of 'snapshots' (e.g. growth, new products, patents) of high technology enterprise in Scotland over the period 1999-2003. Specific question designs (see Section A, Qus.1, 3 and 5 of Appendix, for example), add this dynamic element to the data acquired, which is a useful supplement to the single snapshot one usually gets from pure cross-section evidence. Below, each section of the questionnaire will be considered, in turn, and the nature of the snapshots of Scottish high technology that they imply.

4.1 Performance

As a preliminary to discussion, it should be pointed out that size (e.g. employment, sales) is strongly positively skewed in the sample. The modal, or most frequent size value, is typically low. Indeed, it is sufficiently low as to characterise Scottish high technology firms as 'micro-firms' (i.e. employment size less than 10). Thus the best average measure, or guide, of size to use is probably the median, for which half the firms are above this value, and the rest equal to or below it. The arithmetic average size captures the fact that some of the high technology firms are very large, but given the strong skew in size, is not so revealing as averages usually are, in indicating the typical or 'representative' firm, to use a Marshallian term. We shall therefore pay attention to several average measures in our discussion below.

Whilst average turnover of the high technology firm in the sample was £27m in 1999 (falling to £22m., £17m. and £15m. in years 2000, 2001, 2002, with an estimated average value of £14m. in 2003) it had a median value of £386k in 1999, and a modal value that year of just zero. The latter (zero mode) arises, because many of the firms were development companies, which had not gone to market, and therefore had no sales.

Employment provides quite a revealing measure of size, and is helpful in directing attention to the essentially small scale nature of much of Scottish high technology company activity. The median firm size was 10 in 1999, 2000, 2001 and 9 in 2002 and 2003 (estimated). This is to be contrasted with average employment sizes of 237, 194, 196, 142, and 118 (estimate) over the years 1999 to 2003. Overall, the picture presented by size data - which will be revisited below, in a revealing way, when the

Schumpeterian hypothesis (briefly of scale economies in R&D) is explored - is of a plurality of micro firms (employment size of 10 or less), often still in the development phase, sitting cheek by jowl with a small group of very large mature firms, well seasoned in the development, exploitation and selling of high technology products. Indeed, taking the usual employment yardstick for small and medium sized enterprises (SMEs) of 500 or fewer employees, 94% of the sample were SMEs. In short, Scottish high technology business is *small business and development company business*.

On the face of it, these above findings seem to call into doubt traditional views (e.g. Schumpeter, 1942; Galbraith, 1952) on innovation that would focus on the exploitation of scale economies (e.g. in R&D expenditures). If our typical firms are micro-firms, how can they reap economies of large scale? The distribution of high technology firms, while predominantly of small firms, nevertheless differs significantly from the distribution of the Scottish population of all firms (which is also heavily represented by micro firms). In the sampling period (2003), there were about a quarter of a million business enterprises in Scotland, of which 99% were SMEs, compared to the lower figure of 94% SMEs in our high technology sample. Further, whilst 92% of the Scottish general population of firms are micro-firms (employment $\leq$ 10), this figure in our high technology sample is much lower (only 51%). Indeed, the difference between the general Scottish size distribution of firms, and our sample size distribution of high technology firms, is highly statistically significant (under a χ^2 test) with its test statistic of 267.61 being considerably greater than the critical value of 7.81 ($\alpha = 0.05$]. To conclude on the matter of size distribution, it is indeed clear that whilst most Scottish high technology firms are small firms, they are larger, on average, than in the Scottish population of firms.[1]

The median number of new (or improved) products (goods or services) introduced in the past five years was 3, with an intention to produce 5 new ones in the next five years. Mean numbers of new and intended new products were much higher, at 20 and 34 respectively, reflecting the strong positive skew of the new product distribution. This latter data gives a rather misleading view of the volume of new products. This is emphasised by the fact that the modal number of new products launched was zero, reflecting the large number of development companies in our sample, and the modal number of intended new products was 5, corresponding to the median

Similar remarks apply to the data on the proportion of sales due to new products. As most companies are development companies, the modal proportion for all years (1999-2003) is zero. More revealing, the median rises steadily from 0 in 1990, to 5 in 2000, to 10 in 2001, 23 in 2002 and 30 (estimated) in 2003. This is a refreshing picture of new product development. It suggests that development companies are indeed starting to bring new products on-stream over the sample period.

Reflecting this view of refreshed or new portfolios of products, we find that he proportion of sales attributed to new products (goods or services) rose steadily over 1999 to 2003, being 18%, 26%, 28%, 36% and (estimated) 40% over these years. . None had gone to initial public offering (IPO). As regards generating intellectual property, the modal and median firm had not gone to filing or grant of patent (indeed, 70% of firms had no patent activity), though the average firm thought it might file for patent the following year.[2] The average number of patents filed and granted, respectively, was 4 and 7 respectively, reflecting the much higher level of patenting by the largest companies in the sample. By contrast, it suggests that most companies in the sample, which are typically micro-firms, are protecting this intellectual property, by trade secrecy, see Nasheri (2004), and are increasingly successful at bringing these products to market over the sample period. Indeed, it is our judgement, based on fieldwork amongst these firms, that trade secrecy, with the aim of being 'first to market', was a predominant strategic goal of these firms, and even filing would run the risk of giving too much away to potential rivals. In conclusion, patenting was largely the province of the biggest firm in the sample, and for the software companies copyright, in any case, would be the more relevant way of protecting IP as opposed to patenting. Amplifying this point, Cohen and Klepper (1996) admit to small firm advantages in the generation of new knowledge, but maintain that large firms – as our sample suggests – have an advantage over small firms in the appropriation of returns from innovation (e.g. buying, selling and licensing of IP).

4.2 Resources

Emphasising the small nature of these high technology enterprises mentioned in section 4.1 above, the median number of full-time employees were: 5 technical/ scientific staff, 2 managerial staff, and 1 clerical staff. Mean values were much higher, skewed up but the largest firms, being 34 manual, 15 clerical, 49 technical/scientific, and 16 managerial. These latter figures indicate the high knowledge content of even the largest firms, with technical/scientific staff predominating. Many of these high technology firms did not employ manual and clerical staff (modal numbers are zero in each case). The modal and median outcomes were for all scientific, technical and managerial employees to have university degrees. In other words, these firms were *high-skill*, *high-human capital* and *knowledge* *intensive* in character. Reflecting this, mean training costs per annum were 5% of total labour costs (*viz*. 5% of the 'wage bill'), with a mode of 3%. Thus larger firms commit more resources to training.

The mean annual spend on R&D activity was £842k, about 6% of the mean annual turnover. Thus, larger firms were 'pitching in' considerable resources for innovation, though proportionally small in relation to revenue. For a better idea of what the typical firm was doing, we find that the ration of median R&D spend to median sales is about the same (5%). This may say something about what smaller firms count as R&D, as distinct from development cost, which may not be about invention, but about bringing the fruits of invention to market. Small though many firms in the sample were, 41% of them did have an R&D department. Overall for the sample, 69% undertook innovation expenditure. This consolidates the picture drawn of these high technology firms, with even the smallest of them often being innovation intensive in character. Consistent with this, the median time it took a firm to go from the generation of a new idea to launching a new product or process was 12 months, reinforcing the remark made in Section 4.1 above of the importance of being 'first to market'. The typical firm (i.e. modal firm), which we know to be a small firm, from the standing start of an idea, typically had achieved a product launch in just one year. The mean time to launch was 18 months, reflecting the longer time to launch taken by the bigger firms in the sample. In this sense, the smaller firms seem to have an advantage of nimbleness or speed of action, over the larger firms.

4.3 Collaboration and Cooperation

The sampled firms were asked the location of collaborators with whom they had developed new products (Appendix, Section C, Q.1). The latter term was interpreted widely (cf. Criscuolo and Haskel, 2003; Janz, Lööf and Peters, 2004) to include improved products, processes or organisational structure. Potential collaborators (cf. Chesbrough, 2003; Laursen and Staten, 2006) included: suppliers, customers, competitors, research bodies, government bodies, professional and trade associations and financial institutions or persons. Their locations ranged from local, Scottish and national to European, and the rest of the world.

On average, there was considerable diversity in the location of collaborators. This was true, for example, of suppliers, government bodies, and of professional and trade associations. However, when it came to the important categories of customers and competitors, the great emphasis was international – typically beyond Scotland, to the UK and the EU, and indeed strongly to the rest of the world.

The overall picture on external alliances, which are a measure of networking capabilities, amongst other things, was very positive. Less than five per cent (actually 3.97%) had no alliance, thirteen per cent had only domestic alliances, and the great majority (actually 83%) had both domestic and international alliances. As the literature suggests, for example Almeida and Kogut (1997), firm size may have an influence on such networking patterns. For example, the disadvantages of being small, in terms of resource base, may be complemented by an active network of collaborators which, in effect, enlarges the resource base of an active, small, high technology firm. The firms with only domestic alliances seem to differ from those with both domestic and international alliances in the 'density' of their networking. Thus, the mean number of collaborators or alliances was 34 for firms with both domestic and international alliances; but was just 14 for firms with only domestic alliances. In particular, for 'small' firms, this difference is particularly great – an average of 30 for international and of 11 for domestic. This result is statistically significant [t(51) = 1.874, Prob. Value < 0.05].

Respondents from these high technology firms were also asked how frequently they made contact with their collaborators (or partners in alliance) (see Appendix, Section C, Qu.2) (cf. Yli-Renko and Sapienza, 2001). As judged by mean responses, top of the list, being regarded as 'frequent' contacts, were suppliers and customers (Kaufmann and Todling, 2001). Next came government bodies, followed by research bodies ('average') and professional and trade associations. Financial institutions and competitors were less frequent contacts ('below average'). Again, government bodies seem to be an important source of alliances. Thus, overall, the focus of these firms was on goods and factor market contacts, emphasising the commercial orientation of most firms, despite their high technology character. Supporting this, the numbers of collaborative arrangements was greatest for suppliers and customers, followed by research bodies. So, these firms do aim to buy and sell, above all, but retain their knowledge content, through research contacts.

It is also of note that competitors are a regular type of alliance member. This view of competition differs very much from traditional game theoretic versions thereof, which all emphasise head-to-head rivalry with competitors. Indeed, modern game theoretic models of oligopoly (e.g. Bierman and Fernandez, 1998) focus heavily on Nash equilibrium (which rules out collaboration) and the implied non-cooperative games format. By contrast, we see that these high technology firms are keen to forge alliances with whoever can facilitate early delivery of a new product to market (cf. Zahra and George, 2002; Belderbos et al, 2004). Obviously 'customer is king', and suppliers are crucial to the delivery of new products, but less obvious is the notion of a competitor also being an ally.

Our own fieldwork amongst these high technology firms suggests that a new morphology of small firm conduct is emerging amongst such enterprises. Indeed, they can (and do) compete head-to-head on some product lines[3]; yet they also may collaborate simultaneously on the development, production and sale of innovative new products. This collaboration may well be with the self-same firm with which they currently compete fiercely on other product lines.

Of especial note was the great importance of collaboration with suppliers (cf. Perez & Sanchez, 2002) for the purpose of production. This is natural, especially for the small firms, as to put it in Coasian terms, collaboration is a 'transactionally efficient' alternative to backward integration, Coase (1937). It gets the same, or better, results, compared to integration, because high-powered market incentives mediate between the firm and supplier. These are more unforgiving of performance default (e.g. late delivery, below specification delivery), as compared to 'in-house', or organisational sanctions (e.g. complaining, taking disciplinary action), and hence the efficiency and quality of supply will be better. This is important to these high technology firms, for, as we have seen (in Section 2 above), the time to market, from the development of a new idea, to selling into a new market, is just one and a quarter years. This leaves little space for production default of any form.

Information exchange, with suppliers (cf. Romijn and Albu, 2002), and customers (cf. Kristensson et al, 2002) and then marketing (with customers) were the next most important for the purposes of collaboration. In general, information exchange (which could include, fieldwork suggests, some information *sharing*) was the most ubiquitous purpose of collaboration. The sole purpose for collaborating with government bodies was for R&D – apparently information exchange alone was not important (cf. Rothschild & Darr, 2003; Benfratello & Sembenelli, 2002). Finally, it was significant that recruitment of personnel was typically not a purpose of any collaborative arrangement. The task of recruitment (and retention) of personnel is a matter of great sensitivity. To a great extent the ideas which are important to a small firm's innovative capacity reside in the minds of scientific personnel (cf. Lawson and Lorenz, 1999), and not in published papers, reports or patent applications. Firms are therefore understandably protective of this most valuable of resource, and are loathe to collaborate on job market opportunities.

4.4 Embeddedness

This section of the questionnaire (Appendix, Section D) was concerned with recruitment, mobility, founder's experience, and market 'reach' (for both goods and factor markets).

Most (72%) of the firms in the sample were active in recruiting technical and scientific staff from within Scotland, which is a key indicator of embeddedness. Indeed, the modal and median firms were always recruiting in this fashion. Similarly, another characteristic of embeddedness was that, for some (29%) firms in the sample, staff mobility had encouraged the forming of links with other firms. However, this is a less strong sign of embeddedness as, in principle, mobility out of Scotland, or even out of the UK, could still be compatible with forming linkages. Here, the modal and median firms did not form linkages in response to staff mobility.

Though the activities of founders of these high technology firms were diverse, the typical experience of a founder, prior to the start-up, was within another firm in the UK. That part of the UK was most likely to be Scotland. In that sense, the typical founder is not an inexperienced entrepreneur, but rather one who is seasoned in the world of business. Next in importance, by origin, of founder, was a university, emphasising the knowledge intensive character of many of the small firms. This does not rule out the founder having both business experience, and being from a university background, given that commercialisation is a strength of Scottish universities.

Finally, the last measures of embeddedness considered were the percentage of current sales and current purchases that could be attributed to particular market extent (e.g. local, UK, the World) (see Qu.4, Section D, Appendix), (cf. Lu & Beamish, 2001) for a variety of internationalisation strategies). Clearly, 'embeddedness' is a multi-attribute concept. This is borne out by marked differences in 'embeddedness', for example, for sales, as compared to purchases. In terms of purchases, the firms of our sample are quite heavily embedded. On average, 37% of purchases are nationally based, mostly outside Scotland. Most (nearly two thirds) of purchases are sourced internationally, generally outside Europe (ROW = 37%). By contrast, 44% of sales are made outside Europe, to the rest of the world. The UK and Europe account for about a quarter of sales each. Scotland accounts for just 4% of sales, and the local economy is of insignificance for sales (0.17%). We conclude that, by sales, at least, embeddedness is slight.[4] It is likely that the high technology products of our sampled firms are so specialised that they are largely sold to specialised customers who are at a great distance (e.g. the USA, Japan). Put simply, local and regional markets are too 'thin', in terms of their ability to absorb high technology products, for their sparsely distributed customers to be worth chasing. This has a positive effect on sales strategy, as the firms in the sample are thereby diversified, and not too dependent on local (or even regional or national) market conditions. Thus they might be selling into selected buoyant overseas market segments (and able to price high), at the same time as buying from less buoyant domestic markets, in which case they benefit doubly, from a good revenue flow, allied to effective cost control. Looked at in this way, the strategic benefits are considerable, on a private level, but less so on a public level, especially if cluster policy is seen as partly to foster a local or regional creative milieu, which will in itself be a base for enthusiastic purchasers of high technology products.

4.5 Innovation

On the topic of innovation (see Section E, Appendix) we looked at: innovation expenditure, sources of stimulation for innovation; and factors contributing to, or hampering, innovation. Some aspects of innovation had already been covered in earlier sections of the questionnaire, including: new products and intellectual property (see section 4.1 above); R&D expenditure; and the existence of an R&D department (see section 4.2 above) (cf. Kleinknecht and Reijen, 1995). Given this, this section of our paper rounds out the treatment of innovation, complementing what has already been discussed.

Respondents were asked how much they were spending currently on innovation. This was taken to include the R&D expenditure discussed earlier, plus expenditure on related items, like specialised capital equipment, patent or license fees and training costs. The latter, though frequently sidelined, or even ignored, is important. For example, training often relates to technical staff, the quality of which we know to be of crucial importance to the performance of high technology enterprises (see Reid and Ujjual, 2006). The mean direct expenditure on innovation (viz. R&D + purchase of capital equipment + patents +licenses + training) was £1.22m, which is £378k above the expenditure on R&D alone. This emphasises that much of innovation expenditure is not captured by looking at formal R&D spend alone.

As regards the expenditure on R&D as such, this is heavily influenced by age (which, in turn, correlates positively, and significantly, with size). Reflecting this, about three quarters (actually 75.05%) of the R&D expenditure in the sample can be attributed to firms which are over five years of age. Indeed, 45 per cent of the sampled firms did not have any R&D expenditure (though this does not rule out a variety of other forms of innovation expenditure, as noted above). Even so, expenditure on R&D by the youngest firms in the sample (3 or less years old) were, on average, about ten times higher than for the comparable age group in the whole population of firms. Finally, R&D spend per employee (i.e. R&D 'intensity') was relatively high in Scotland across all sectors, though typically less (by sector) than for the UK as a whole. For example, R&D intensity in the pharmaceuticals sector was £42k in Scotland, but £48k (on average) in England. Overall, the R&D intensity for our sample, which stood at £7.1k, was higher than in most UK sectors (e.g. compare this to computer services at £1.1k, and aerospace at £1.9k), suggesting Scotland focuses relatively more attention on supporting high R&D intensity firms.

Concerning the importance of sources of information (Appendix, Section E, Qu.2) for stimulating innovation, in general, within the firm, internal sources (like R&D staff, and marketing staff) and market sources (like customers, suppliers, and even rivals) were considered especially important. Educational and public bodies (like government agencies and universities) were considered to be of only average importance in stimulating innovation. As regards stimulating innovation, of predominant importance were improved products (including extended product range) and increased (or retained) market share. Increased productivity was rated as of average importance, and better compliance (e.g. to regulations) was, perhaps understandably, rated as relatively unimportant to stimulating innovation. It was not, however, off the map, as some high technology firms do ‘make markets’ out of new regulations, especially in the environmental domain. A quite different set of factors came into play when consideration was given to what hampered innovation within the firm. Here, economic factors (like costs, finance, and uncertainty) were the major concern of firms, for their negative impact on innovation, followed by firm specific factors (like a lack of skilled personnel). From a policy standpoint, the main hampering factors are not always amenable to control or amelioration, whereas firm specific factors, though of lesser importance, are at leas in principle controllable. Other factors impeding innovation (but rated as being of less than average importance) included regulation, taxation and imitation by rivals.

4.6 Conclusion on key results

Even without analysis of any sophistication, the results of the questionnaire are highly informative. They paint a rather healthy picture of high technology enterprise in Scotland. Such firms are small, but innovation intensive, and international in outlook (including in their collaborative activities and in the markets into which they sell). They embody high levels of human capital, and are quick to get new products and services to market. Unless they are large and mature (which are the minority of firms in the sample), they do not take many steps, in a formal sense, to protect intellectual property, which suggests, given the short time to market, that trade secrecy is important (cf. Lerner et al., 2004).

Whilst firmly embedded on the factor market side, our sampled firms are scarcely embedded on the goods market side, with most principal markets being outside Europe, let alone the UK. Collaborative arrangements focus on customers and suppliers, with their purpose heavily directed towards information exchange and marketing. Size (and its correlate age) is very important. Thus the size distribution (e.g. the micro firm / SME / large firm distinction) accounts for a lot in explaining the variety of forms of conduct observed.

For this reason, the further statistical and econometric work, which we report upon below, focuses on size as a key attribute. It does so with reference to: rate of growth (including convergence to an 'optimal' firm size); and scale economies in innovation (and specifically in R&D). In the latter case, for example, it asks whether these effects are local and/or global, so far as size is concerned. In a formal sense, these issues will be examined under headings which test the hypotheses of Gibrat (1931) and of Schumpeter (1934).

5. Statistical and Econometric Evidence: Gibrat's Law and the Schumpeterian Hypothesis

5.1 Gibrat's Law

As described in Section 4.1 above, the questionnaire instrument allowed us to measure firm size over the years 1999 to 2003, using three different measures of size: turnover (R), employees (L) and exports (X). In turn, the ratio of employees to turnover provides an (albeit simple) measure of labour productivity (L/K). These data are used to test the 'Law' propounded first by Gibrat (1931), which says, as applied to businesses, that the rate of growth of a firm is independent of its size. The Gibrat Law can be embedded in the more general model

$$S_{t+1} / S_t = \gamma S_t^{(\beta-1)} \varepsilon_t \qquad (1)$$

Where S_t measures size in time period t, γ and β are constants, and $\{\varepsilon_t\}$ is a sequence of independently distributed positive random variables. The Gibrat case occurs when

$\beta = 1$. This is the null hypothesis. The usual alternative hypothesis is $\beta < 1$, which is to say that smaller firms grow faster than larger firms. Equation (1), in estimable form, can be expressed in natural logarithms as:

$$\ln S_{t+1} = \ln \gamma + \beta \ln S_t + \ln \varepsilon_t$$

or, more simply

$$s_{t+1} = \alpha + \beta s_t + \mu_t \qquad (2)$$

where $s_{t+1} = \ln S_{t+1}$, $s_t = \ln S_t$, $\alpha = \ln \gamma$ and $\mu_t = \ln \varepsilon_t$. If a least squares estimate of (2) is written as

$$\hat{s}_{t+1} = \hat{\alpha} + \hat{\beta} s_t \qquad (3)$$

the equilibrium log size (s^*) can be solved as:

$$s^* = \frac{\hat{\alpha}}{(1-\hat{\beta})} \qquad (4)$$

which is achieved if $0 < \hat{\beta} < 1$. The 'passage to equilibrium' of a firm, given a start-up size of s_0 is determined by the 'equation of motion' (3), which can trace out the log size period by period. Thus

$$\begin{aligned} s_1 &= \hat{\alpha} + \hat{\beta} s_0 \\ s_2 &= \hat{\alpha} + \hat{\beta} s_1 = \hat{\alpha} + \hat{\beta}(\hat{\alpha} + \hat{\beta} s_0) \\ &= \hat{\alpha} + \hat{\alpha}\hat{\beta} + \hat{\beta}^2 s_0 \end{aligned}$$

and so on. To illustrate, if the year 2001 is represented as the base year (year 0), and the next measurement is in 2003 (year 2), the estimated version of equation 3 (using 112 observations) is given as:

$$\hat{s}_{t+1} = 1.247 + \underset{(t=23.37)}{0.843 s_t} \qquad R^2 = 0.8323 \qquad (5)$$

where s is log turnover. The β coefficient is positive, and significantly less than unity (prob. value = 0.000). The implied equilibrium log size (s^*) is 7.96 which translates into size (S^*), in millions of pounds, as £2.86m.

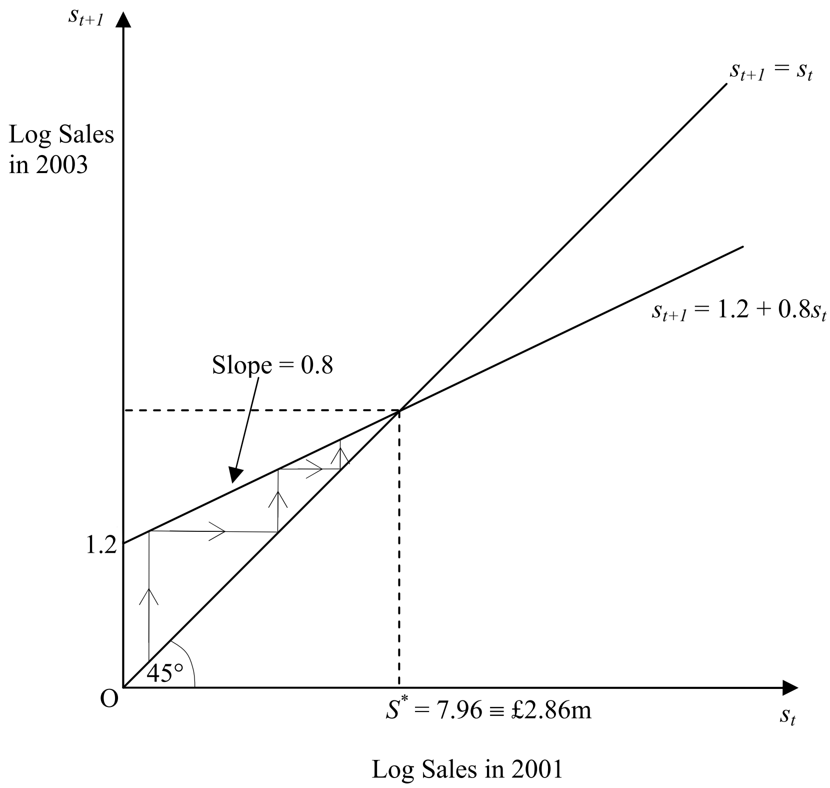
[Figure 1 near here]

Figure 1 presents a so-called phase diagram, where the 45° line represents equilibrium, as along it $s_{t+1} = s_t$, which is to say size does nor vary period by period. The estimated equation (5) is represented approximately by log s_{t+1} = 1.2 + 0.8 log s_t. The equilibrium size (s^*) is identified, as is a possible path to equilibrium, by arrowed lines from a lesser starting value.

To summarise, the data suggest a stable dynamic adjustment process (as $\hat{\beta} < 1$) with an equilibrium sales value that is plausible for the small firms of our sample. Of course, this extrapolation assumes no change in the firm (e.g. in terms of innovation, corporate form), whereas the reality may be a firm which may mutate (e.g. may enjoy enhanced productivity over time), which can significantly raise the implied equilibrium size, in terms of sales (and of variables which correlate with it, like employment).

[Table 3 near here]

Similar tests of Gibrat's Law were made using different time intervals (e.g. 2000 to 2003) and different size measures (e.g. employment, labour productivity). The general finding (see Table 3, Column 2) was that $\hat{\beta}$ was less than unity, but was greater (i.e. closer to unity) the longer the time period used for estimation. The latter



Least Squares Regression of Gibrat's Law

Figure 1

effect is what one would expect: $\widehat{\beta}$ gets larger as is accommodates to the greater scope for adjustment by firms that may occur over longer time periods.

Table 3: Range of values of $\widehat{\beta}$ and S^*

Size Measures	$\widehat{\beta}$ (Slope)	S^* (Equilibrium Size)
Turnover	0.84 – 0.91	£2.9m - £13.4m
Employment	0.89 – 0.94	109 – 137
Productivity	0.62 – 0.78	55.7 – 86.5

Note: Equilibrium size (column 3) has been converted from s^* (log size) to S^* (size in its natural units viz. GBP, full-time employees, and GBP per full-time employee, respectively)

Table 3 also provides comparisons of $\widehat{\beta}$ estimates (column two) for the three different size measures (column 1), turnover (R), employment (L), and labour productivity (R/L). There is a faster rate of adjustment for labour productivity, compared to sales and employment, confirming what was suggested above, namely that the firm itself is changing over time, and is likely to become more productive (e.g. because of 'learning by doing' effects). We tested for heteroskedasticity (see McCloughan, 1995) for these equations, and generally did not reject the null hypothesis of homoskedasticity (e.g. in the employment case $\chi^2 = 1.76 < 4.605$, for $\alpha = 0.01$). However, there was some evidence of heteroskedasticity for some variants of the productivity equation. Even with heteroskedasticity, we do get unbiased estimates.

A further point to note is that the equilibrium sizes (column three, Table 3) are highly plausible. Thus it is credible that small firms with an average size of £750k in 2003 should grow on, some years later, to an equilibrium size of between £2.9m - £13.4m. True, this would imply a small scale of operation (on average), but as we have observed most high technology firms in Scotland *are* small. This is reinforced by the equilibrium employment figures (column 3, Table 3) which range from 109 to 137 full-time employees. This puts the typical high-technology firm in Scotland firmly in the small and medium-sized enterprise (SME) category – indeed towards the smaller end of that size class.

To conclude the discussion of Table 3, it suggests a credible equilibrium level of productivity per employee (R/L). The range is from £55.7k to £86.5k which can be compared with the evidence to hand. From the questionnaire data (see Qu.1, Section A of Appendix), mean revenue per employee (our productivity measure) was £103k per employee in 2002, and the estimated figure for the same variable, in 2003, was £118k per employee, both of which are perhaps on the high side (probably because of the presence of some very big firms in the sample), but certainly achievable by many firms in the sample. On the other hand, the median data, which better represent the micro-firm element in the sample, suggest a much smaller productivity. For example, the median labour productivity in 2002 is £36.7k, and, using the estimated figure for 2003, is £33.9k. All of this evidence points to quite small scales of operation for our sample of Scottish high technology firms, both in terms of actual size, and in terms of predicted equilibrium size. In turn, this SME status seems to be consistent with relatively high levels of labour productivity. This then prompts the question: what has happened to the supposed advantages of scale in undertaking R&D? Are there not economies of scale to be reaped by large industrial research facilities? This is a question to which we now turn, in the next section, on the Schumpeterian Hypothesis.

5.2 The Schumpeterian Hypothesis

It was Joseph Schumpeter who, in several works, including his *Capitalism, Socialism and Democracy* (1942), argued that, because of scale economies in innovation, big business had superior innovative performance to small business. This argument was subsequently popularised and elaborated by JK Galbraith in his *American Capitalism* (1952) and other works. However, neither Schumpeter nor Galbraith were econometric analysts, nor did they provide econometric evidence for what we are calling here 'the Schumpeterian Hypothesis'. In reality, their evidence was informal and rather flimsy, though work of others has subsequently provided more substantial evidence in support of the Hypothesis. For example, Barber, Metcalfe and Porteous (1989) have emphasised the superior opportunities large firms have for exploiting complementarities between R&D and manufacturing processes; and Stinchcombe (1990) has emphasised size advantages, like the availability of internal finance, the spreading of fixed costs of innovation, high economies of scale in the industrial manufacturing side of innovation, and scope economies between the latter and R&D itself.

Opposed to the Schumpeterian view is what Acs and Audretsch (1990) have called the 'New Industrial Organization', as applied to SMEs, in contrast to large corporate enterprises. This view has been built up further by Acs and Audretsch (1991), and a wide range of followers, including Rothwell and Dodgson (1994), Cohen and Klepper (1996), Tether and Storey (1998), Love and Roper (2002) and Freel (2003). A complex web of arguments is constructed, indicating why small firms might have advantages over large firms in innovation performance, including: flexibility; creativity; generation of new knowledge; lack of bureaucracy; superior incentives for innovation; and better protection of intellectual property. All this is a matter of addressing analytical arguments to support what, by the end of the 1980s, was becoming to be an accepted empirical finding, namely that, adjusting for scale, small firms have higher innovative performance than large firms. Thus Baumol *et al* (1984) had found small firms displayed a better patenting performance than large firms, and Oakey, Rothwell & Cooper (1988) had found that small firms had increased their relative share of innovation since World War II. Pattier (1988) focused more on deficiencies in large firm innovation performance, through balkanising their monopoly position and shelving opportunities for innovation, which made their relative performance decline as compared to smaller firms. The latter had no monopoly power to exert, and rapidly had to embrace innovative opportunities, or risk being driven to the wall by eager small competitors, who were hungry for a share of the action in new, emerging markets.

The position we take in this paper is that it may be possible to conceive of *both* views as being correct – that deriving from Acs and Audretsch (1990), championing the nimble, niche playing, small firm as innovator, and that deriving from Schumpeter (1942), championing the large scale, diversified giant as innovator. If the truth be told, Schumpeter fully analysed both cases (see McCraw, 2007). The first case, for small entrepreneurial firms, was espoused in his *Theory of Economics Development* (in English in 1934, but much earlier, 1911, in German); and the second, for industrial giants, was espoused in *Capitalism, Socialism and Democracy* (1942). As Langlois (2003) has recently put it, there were 'two Joseph Schumpeters', each relating to distinct historical epochs, the first, stretching back into the nineteenth century, and the heyday of small business capitalism, and the latter relating to mature large scale industrial capitalism, with large corporate research facilities. In the latter era, there emerged the prospect of routinised paths to innovation, steered by a highly gifted cadre of technocrats (famously to be described by Daniel Bell (1974) as the 'technocracy'). What we will argue is that the early Schumpeter has now become more relevant again, with its focus on agile, small entrepreneurial firms; and that this can, indeed, sit side-by-side with what we now know as the Schumpeterian Hypothesis, which relates to the 'industrialisation' of innovation and the exploitation of both scale and scope economies of innovation in very large corporate firms.

The method we use builds on the earliest work of Comonor (1967), which used regression models to test whether firm size and innovativeness were positively associated , as developed by the likes of Grabowkel (1968), Fisher and Temin (1973), Loeb and Lin (1977), Baumol *et al* (1984), Acs and Audretsch (1991) and Reid *et al* (1996). Indicative of the general findings of these works was the study of Pavitt *et al* (1987), which found that, generally, micro-firms and the largest corporate entities had the greater innovation performance, though the strength of this relationship varied across industries. Here, we propose to take that finding a step further, and argue for *both* small scale *and* large scale advantages in innovation.

The basis for the modelling is a polynomial function of the third degree (*viz*. cubic function) for exploring innovation intensity, of the form:

$$I = \beta_0 + \beta_1 S + \beta_2 S^2 + \beta_3 S^3 + \varepsilon \qquad (6)$$

where I is an innovation measure, the β_I are regression coefficients, S is a size measure (e.g. sales, employment) and ε is a stochastic disturbance term.

Equation (6) presents a wide variety of empirical possibilities, in terms of forms in which it can be estimated, e.g. depending on the choice of dependent variables. As dependent variable, we can use a variety of patent and product development measures of innovation. Here, the two we focus on are: the ratio of patents granted to sales (which we call Patent Intensity), and the ratio of Sales to R&D staff (which we call R&D Productivity). The size variable (*S*) for the independent variables of equation (6) will be taken to be employment, partly because this is a natural size measure, but also because this avoids the potentially spurious correlation with the dependent variable (which involves sales, either in the numerator or denominator, in each case) which would arise were sales also to be used as the size measure in the regression.

The estimated coefficients for these two variants of equation (6) were as in Table 4. Prob values are in brackets under coefficients. In each case, the linear coefficient ($\hat{\beta}_1$) is positive and significant, the quadratic coefficient ($\hat{\beta}_2$) is negative and significant, and the cubic coefficient is positive and significant. The overall fit, judged by an F-test, is also good, and highly statistically significant in each case.

Table 4: Estimates of Cubic Innovation Equation by Least Squares Regression

Coefficients	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
1. Output Innovation Measure	$1.21.10^{-4}$ (0.000)	$-7.72.10^{-8}$ (0.001)	$1.06.10^{-11}$ (0.001)
Patent Intensity = $\frac{\text{Patents Granted}}{\text{Sales}}$			
$R^2 = 0.123$			
F = 6.189 Prob.Value = 0.000			

Coefficients	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
1. Input Innovation Measure	1.113 (0.000)	$-7.28.10^{-4}$ (0.001)	$1.04.10^{-7}$ (0.002)
R&D Productivity = $\frac{\text{Sales}}{\text{R\&D Staff}}$			

$R^2 = 0.133$

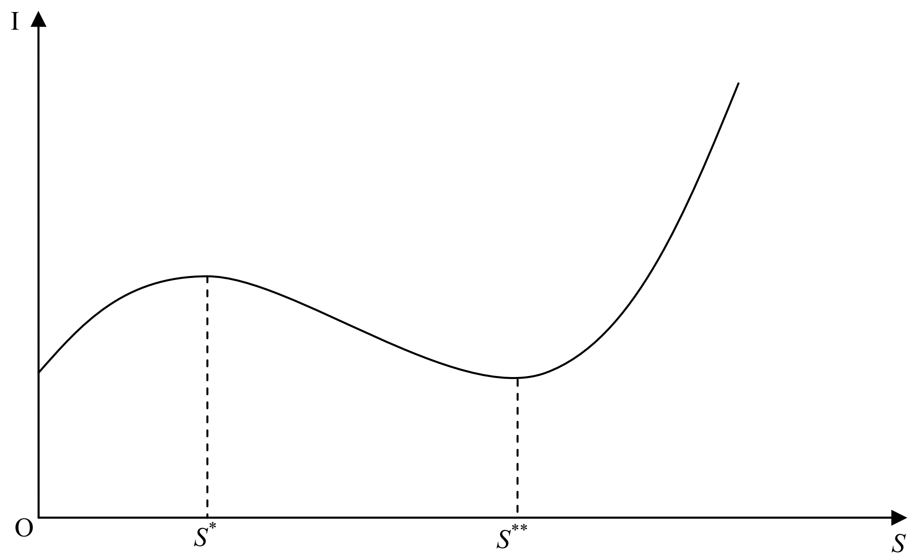
F = 6.318   Prob.Value = 0.000

Notes:

(a) For regressions, size variable (*S*) is always employment.
(b) For regression 1, dependent variable is Patent Intensity; for regression 2, dependent variable is R&D Productivity.
(c) Prob. Values are given in brackets, under each coefficient estimate.

[Figure 2 near here]

Cubic innovation equations of the form of equation (6) were estimated in eight variants, apart from the two reported upon in Table 4. The various innovation measures used (both of inputs and outputs) depended upon related variables like intensity of patents filed (output measure) and expenditure intensity per employee (input measure). They all suggest a generic form to the cubic equation, as represented in Figure 2. Across the seven estimates made, the size variable S^*, measured in



Note: (a) *I* is an innovation measure (e.g. patent intensity); *S* is a size measure (e.g. full-time employees)

(b) At S^* the cubic attains a (local) maximum; and at S^{**} it attains a (local) minimum.

Cubic Relation Between Innovation and Size

Figure 2

employment, fell within the range of 867 to 1,637 employees, with most being around 1,000, and indeed the average being 1,075. S^* is that size of firm for which innovation intensity is at a local maximum. We observe, first, that this is quite a large figure, approximately twice the usual upper limit for an SME. However, it falls far short of the employment size of large corporations, which frequently run to tens (or even hundreds) of thousands. Against that perspective, 1,000 employees is still on the small side. To the right of S^* lies S^{**}, which denotes both that size at which innovation is at a local minimum; and also that size beyond which the estimated function becomes both increasing and convex. That is, beyond S^{**}, the Schumpeterian Hypothesis is supported. The typical value of S^* for the estimates is around 3,000 and, indeed, the average value for this is 3,169 employees. So, the Schumpeterian Hypothesis is supported, but only at very large business sizes. At the same time, and without contradiction, we can say that the New Industrial Organization view is also supported, with the local maximum for innovation being at the level of 1,000 employees.

It may be noted that this size (S^*) is considerably larger than the equilibrium firm size which was suggested when the Gibrat's Law was being tested. There, the equilibrium employment sizes were all above 100 employees, but less than 150 employees. However, it was observed that typically the equilibrium size rose, the longer the time interval over which the Gibrat model was tested. This is partly a purely formal effect (the more the time, the more the opportunity for change), but also is an intrinsic effect, in that the small firm itself is often changing over time, notably in its organisational form, but also in many other key aspects, including IT usage, product range, in-house and out-house staff training etc. To each of these forms, there exists an implied long-run equilibrium size (see Figure 3 below). Now, it may be that in small firms which are not high technology based this pace of change is slower, and may not occur at all.

To a fair extent, this must be so, as most small firms do *not* grow to a considerable degree: only the 'gazelles' or 'ten percenters' are noted for market growth[5]. However, the typical technology based firm is different from most firms. It has a much higher human capital content (e.g. on average, in the sample, all employees were college graduates), and a greater focus on training (about ten per cent of labour costs, on average). Further, it has a far-reaching network (the modal collaborator being in the 'rest of the world'). Therefore, for such firms, one would expect relatively rapid organisational change, superior access to outside finance, and generally, a smarter, more agile, small firm strategy. For such firms, growth to an equilibrium size of 1,000 employees may be by no means implausible.

However, what our model [of equation (6), Table 4 and Figures 2 and 3] suggests is that growth from this size to very much larger sizes (suggested as being above 3,000 employees) may not be easy. There is a right-skew to the cubic curve (i.e. it is not symmetric about S^*), so the distance to go, in order to reach the threshold of size at which the Schumpeterian effect 'kicks in', namely S^{**}, is twice the distance travelled in going from start-up to S^*. Not only that, going from a scale of zero to S^*, involves increasing innovation performance which will please owners, stockholders, managers, backers and a variety of other stakeholders. However, going from S^* to S^{**} involves a diminution in innovation performance, precisely because the evidence is that S^* is the implied SME equilibrium scale of operation, or 'local equilibrium', beyond start-up.

Given this, one might then ask how such growth can be, and has been, attained by the research giants of today. One answer might be 'strategic vision' – the possibility of seeing beyond a long period of declining innovation performance while scale is built up, so it becomes possible to reap the full benefits of scale and scope economies and complementarities, and thereby to achieve the advantages that Schumpeter (1942) emphasised. The other answer, more plausibly, is that firms moving rapidly up the innovation-performance trajectory will become attractive acquisitions by larger firms which are themselves facing falling innovation performance. Alternatively, but in the same spirit, the firm growing rapidly towards S^* (then beyond) may seek merger possibilities with several similar sized potential partners. The strategy here is to simply 'buy-in' (rather than 'build-up') to the scale economies and complementarities that are sought, in order to join the biggest players in the technology game.

6. Conclusion

This paper reports, in a preliminary way, on a new set of findings into the growth and early performance of high technology firms in Scotland. We have shown how our sample was constructed, and that it is representative of the whole population of such firms in Scotland. The principal sectors examined have been five in number: microelectronics, life sciences, digital media, optoelectronics and software. The key aspects examined, for firms in this sample, using a postal and e-questionnaire, were: performance, resources, collaboration & cooperation, embeddedness, and innovation. A total of 836 firms was examined, over the period 2003 to 2004. Summary results have been provided for all factors explored in the questionnaire, and more detailed consideration was given to statistical and econometric testing of Gibrat's Law and the Schumpeterian Hypothesis.

From the questionnaire as whole, the principal discoveries were:

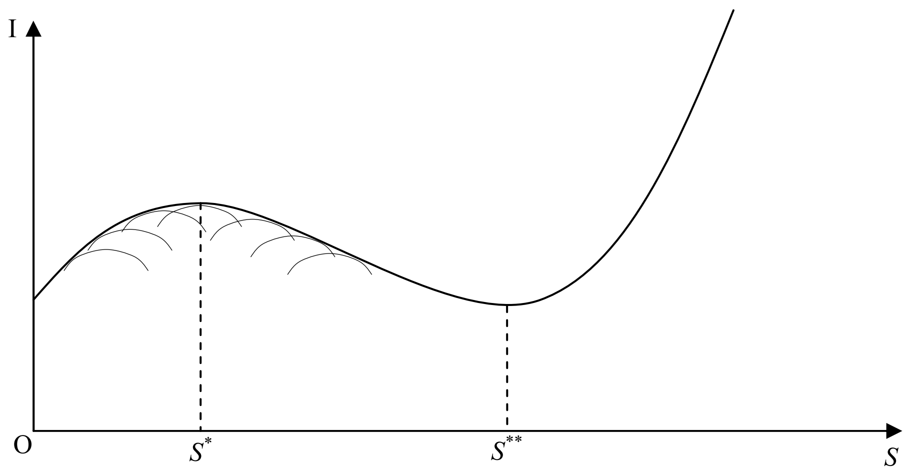
- The Scottish high technology sector is dominated by small and medium sized enterprises.

- Such firms were knowledge intensive and typically manned by college and university graduates.
- They typically had diverse collaborators, frequently extending overseas, often beyond Europe.
- These firms were well embedded in Scotland, in terms of staff recruitment and to a fair extent, in terms of purchases; but were not embedded in terms of sales.
- Both R&D expenditure and, more broadly, innovation expenditure were high, with the greater absolute contributions being made by older (and larger) firms, but with small firms doing well in terms of proportional contribution.
- The main impediments to innovation were economic factors (like costs and finance) and firm specific factors (like levels of skilled personnel).
- Firms were quick in getting new products to market, usually under the veil of trade secrecy, rather than formal methods of IP protection (which was more the province of the largest firms).

In terms of statistical and econometric analysis, our main focus was on evidence concerning performance and innovation. Performance was examined in terms of growth, especially sales growth and employment growth. The sampled firms displayed high growth rates, which were themselves found to depend (negatively) on size. Thus the greater the size, the lower the growth rate (this rejects the simple Gibrat's Law). This implies an equilibrium size of firm, but one which is contingent on the form of the firm. Assuming no change in the firm (e.g. though innovation), this equilibrium size was estimated to be about 120 employees. However, such firms do indeed change their form considerably over time, through R&D, investment in plant and equipment, training and through organisational innovation. All such changes will raise the implied equilibrium firm size, and indeed this effect may well be occurring continuously, rather than periodically.

Figure 3 near here

Growth was linked to innovation performance, in terms of both input and output measures of innovation. A cubic curve, relating innovation to size, was estimated on



The Envelope of Innovation Performance

Figure 3

our cross-section of firms, and this functional form gave a good fit to data. It suggested the relationship shown in Figure 3. This shows the innovation (I) and size (S) relationship as being of an inverse S-Shape, initially concave and then convex. On this performance curve, a local optimum can be found for the size of the high technology firm, which is at about 1,000 employees. This is very much higher than the optimum implied by extrapolations based on the modified Gibrat model (which is about an eighth of this). However, those extrapolations were based on a *given* form of firm, which in the case of high technology firm is highly unlikely to be the case, given that they specialise in innovation. More likely, for each given form of firm, there is an implied equilibrium size. As this form changes, by the innovation process itself, so the implied equilibrium rises. This is illustrated in Figure 3 by a *family* of optimum firm sizes, for which the I(S) curve is an upper envelope.[6]

Finally, beyond S^{**} (at very large scales, involving thousands of employees) we do indeed find evidence in support of the Schumpeterian Hypothesis, that is to say, evidence of considerable economies of scale in innovation. It is suggested that, for mature high-technology firms, movement from size S^{*} to sizes beyond S^{**} may not necessarily be incremental, but may involve activities like trade sales, takeovers and mergers. Thus our findings do not suggest a contradiction between an optimal small firm size, and the prospect of potentially unlimited scale economies in innovation, but do suggest that movement from the former to the latter may require some radical shift in the growth process e.g. from internally generated growth, to growth by acquisition and mergers. This, in turn, suggests a new hypothesis, to be tested in future work.

Footnotes

This research was made possible by a ScotEconNet grant, for which the authors express thanks. A number of people have been of assistance in helping to improve an earlier version of this draft, including Dr Patrick McCloughan of Indecon International Consultants who gave us detailed comment, from which we have benefited. The paper has also benefited from discussion in the Brown Bag seminar series of the School of Economics & Finance, University of St Andrews. The authors remain responsible for such errors of omission or commission that this paper may contain.

1 It should be noted that comparisons about size should also take age into account, for the two are positively correlated (Pearson's Correlation Coefficient = 0.268, which is significant at the 1% level). To illustrate, in our sample, the large firms were all over five years old, and SMEs were predominantly young, of which the youngest were the micro firms.

2 This masks a highly skewed distribution of patenting activity within the sample. About 20% of the sample as a whole had filed for patents and about 11% had achieved grant of patent. This conceals the fact that only 2% of micro firms had patented. The situation was markedly better for the next size bracket and 25% of small and medium sized firms had patented. Finally 73% of large (i.e. employment > 500) firms had patented, emphasising their predominant role in the protection of IP in an absolute, if not a proportional, sense..

3 Very often, this is a safe, relatively standard, tried and tested product, which is used largely for revenue generation and is now no longer leading-edge technology.

4 In terms of expert performance, there was a greater internationalisation of activity by the sampled firms, with 60% of trade being outside the UK, as compared to 46% for all Scottish firms. This difference in export intensity is statistically significant.

5 'Gazelle' is a term due to Birch (1981) and Storey (1994) introduced the term 'ten percenter' with a similar intent, in reference to the small proportion (10% or less) of high growth firms in any start-up sample.

6 Let $I = I(S,k)$ denote the relationship between innovation (I), size (S), and a scale parameter (k). The latter denotes, continuously, the different possible sizes of the innovating firm (e.g. a micro firm, a small firm, a medium sized firm). Each small curve below the envelope in Figure 3 is defined for a distinct k. Let $I = I(S,k)$ be written in so-called implicit function form as $F(I,S,k) = 0$. Then the envelope curve in Figure 3 is obtained by eliminating k from the implicit functions $F(I,S,k) = 0$ and $F_k(I,S,k) = 0$ where F_k denotes partial derivative with respect to k.

APPENDIX - POSTAL QUESTIONNAIRE

Section A Performance

1. How large has your firm been in the last five years?

	1999	2000	2001	2002	2003(Estimate)
Turnover (£)	______	______	______	______	______
Employment	______	______	______	______	______
Exports (£)	______	______	______	______	______

2. (a) How many new or significantly improved products (goods or services) have you introduced in the last five years? ______

   (b) How many do you intend to introduce in the next five years? ______

3. What proportion of your sales (%) are due to these new products (goods or services)?

	1999	2000	2001	2002	2003(Estimate)
Sales	______	______	______	______	______

4. (a) If you have gone to IPO (Initial Public Offering), when was that? mm/yy ______

   (b) If you intend to go to IPO, when might that be? mm/yy ______

5. How much patenting activity have you undertaken?

	1999	2000	2001	2002	2003(Estimate)
Grant of patent	______	______	______	______	______
Filing of patent	______	______	______	______	______

Section B Resources

1. How many full-time staff do you have?

Manual ______
Clerical ______
Technical/Scientific ______
Managerial ______

2. What percentage of these staff types have a university degree or the equivalent?

Technical/Scientific staff ______ (%)
Managerial staff ______ (%)

3. What are your training costs as a percentage of your total labour costs? _________ (%)

4. What is your current annual R&D expenditures? £_________000s

5. Do you have a R&D department? Y / N

6. On average, how long do you take from getting a new idea to launching of a new product or process? __________ (months)

Section C Collaboration And Co-operation

1. Firms use collaborators to develop new or improved products, processes or organisational structures. Where are your collaborators located? (Please tick)

Collaborators \ Locations:	Local	Scotland	UK	Europe	World
Suppliers	____	____	____	____	____
Customers	____	____	____	____	____
Competitors	____	____	____	____	____
Research bodies	____	____	____	____	____
Govt. bodies	____	____	____	____	____
Professional / Trade	____	____	____	____	____
Financing	____	____	____	____	____

2. How frequently do you have contact with them?
(Mark on a scale of 1 to 5, where 1 = infrequent and 5 = frequent; mark 0 if no contact at all)

Suppliers	____
Customers	____
Competitors	____
Research bodies	____
Govt. bodies	____
Professional / Trade	____
Financing	____

3. How many collaborative arrangements do you have for each purpose they serve? Enter the number (e.g. 1, 3, 10 etc.).

Collaborators \ Purposes:	Capital	Information	IP	Production	Recruit	R&D	Marketing
Suppliers	____	____	____	____	____	____	____
Customers	____	____	____	____	____	____	____
Competitors	____	____	____	____	____	____	____
Research bodies	____	____	____	____	____	____	____
Govt. bodies	____	____	____	____	____	____	____
Professional / Trade	____	____	____	____	____	____	____
Financing	____	____	____	____	____	____	____

Section D Embeddeddness

1. Do you actively recruit technical and scientific staff within Scotland? Y / N
2. Does staff mobility encourage you to form links with other firms? Y / N
3. What was the activity of your firm's founder before start-up? (Tick one below)

	Self-employed	Unemployed	University	Govt. research lab	Another firm
Scotland	____	____	____	____	____
UK	____	____	____	____	____
Abroad	____	____	____	____	____

4. What percentages (%) of your current sales and purchases are in each of these markets?

	Local	Scotland	UK	Europe	World
Sales (%)	______	______	______	______	______
Purchases (%)	______	______	______	______	______

Section E Innovation

1. How much do you currently spend per year directly on innovation?
   (e.g. R&D + purchase of capital equipment + patents + licences + training)

   Innovation expenditure £ __________000s

2. How important are these sources of information in stimulating innovation in your firm?
   (Mark on scale of 1 to 5, where 1 = unimportant, 5 = very important and mark 0 if irrelevant)

   Internal (e.g. R&D staff, marketing staff) ____
   Market (e.g. customer, supplier, competitor) ____
   Educational & Public (e.g. govt. agencies, universities) ____

3. How important are these objectives in stimulating innovation in your firm?
   (Again mark on the same 5-point scale)

   Increased productivity ____
   Improved products (extended product range) ____
   Increased or retained market share ____
   Better compliance (e.g. to regulations) ____

4. How important are these factors in hampering innovation in your firm?
   (Again mark on the same 5-point scale)
   Economic (e.g. cost, finance, pay-off uncertainty) ____
   Firm specific (e.g. lack of skilled personnel) ____
   Other (e.g. regulations, taxation, imitation by others) ____

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