KNOWLEDGE TRANSFER, ENTREPRENEURSHIP AND ECONOMIC GROWTH: SOME REFLECTIONS AND IMPLICATIONS FOR POLICY IN THE NETHERLANDS

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Abstract

This paper provides an overview of the relationship between entrepreneurship university spin-off activity and economic growth. It suggests the need for a diversified university structure, and that spin-offs are a misleading measure of the most important activity for technology transfer which remains the training and education of highly qualified scientists and technologists. It argues that a linear approach to the innovation process positioning basic science at one end of a chain and commercialization at the other is misleading. The reality is more complex and incorporates important areas of activity where consideration of use and the pursuit of basic science go hand in hand.

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1. Introduction

In this paper I wish to provide some reflections on knowledge transfer concerned with ‘innovative entrepreneurship’. This is potentially a very broad canvas, especially since the terms ‘innovative start up’ and ‘innovative entrepreneurship’ are themselves imprecisely defined. There is certainly a large and rapidly growing literature on new knowledge based firms and their relationship with the science base. That literature and the lessons that may be drawn for policy have been the subject of several overviews at an international level (see e.g. OECD (2002) and for the Netherlands the references and discussion in van der Laag and Snijders (2003)).

There is also an expanding recent literature relating to the institutional design and management of incubators and spin-off[1] programs, and their incidence and impact in Europe and the OECD generally[2]. It is therefore neither useful nor possible to attempt a comprehensive review of that kind here, nor to provide a detailed assessment of Dutch policy in this area. Instead, I will be deliberately selective. I will reflect on three issues, which in my view have important implications both for policy towards university related new technology based firms, and for what growth outcomes may generally be anticipated from the kind of approach currently adopted in the Netherlands.

The first of these three issues is the interpretation to be placed on the relative role and significance of new firms and high technology sectors in recent US growth and productivity performance, and its policy implications. The second is the lesson to be drawn for the relative importance of new and existing firms in productivity performance in general and across different technology based sectors from the growth experience of the OECD economies. My discussion draws on a number of recent studies based on decompositions of macroeconomic data for the USA and the OECD. These have, in my view, important implications for the scale and direction of effects we can expect from technology transfer policies targeted at new and small businesses in technology based sectors. The third issue is the policy implications that may be drawn for university based commercialization and spin-out policy drawing on the experience of the USA. This bears in particular upon the issues of attitudinal and cultural constraints on science industry relations in the Netherlands, which have been emphasized recently. It also bears on the incentive and institutional problems, which arise in attempting to devise policies to strengthen the links between industry and the science base (Muizer (2003)).

2. Technology Transfer, Entrepreneurship and Economic Growth

The strength and nature of the link between the growth of economic welfare and the development and exploitation of scientific and technological understanding has become a central theme in macroeconomic, industrial and technology policy discussions. At the same time there has been an increasing emphasis on the role which new technology based firms and entrepreneurship play in the technology transfer process (OECD (2001a) (2002)). These developments are closely related to the recent objective set at the European Council in Lisbon in March 2000 of the EU becoming the most competitive and dynamic knowledge-based economy in the world, capable of sustainable growth, more and better jobs, and greater social cohesion. It is also reflected in policy analyses for the UK, the USA, and the OECD in general.

> ‘The nation that fosters an infrastructure of linkages among and between firms, universities and government gains competitive advantage through quicker information diffusion and product deployment’ *(US Council on Competitiveness (1998))*

> ‘In an increasingly knowledge-driven global economy invention and innovation are critical to Britain’s long-term competitiveness. This requires a virtuous circle of innovation: from the very best in science, engineering, and technology in universities and science labs to the successful exploitation of new ideas, new science, and new technologies by businesses’ *(DTI, H.M. Treasury, DFES, (2002))*

> “Young technology based firms play a key role in linking science to markets. Governments rightly attach priority to encouraging spin-offs from public research to stimulate innovation” *(OECD (2002))*

In the particular case of the Netherlands the emphasis upon technology transfer related activities has been reinforced, against this general background, by a series of evidence-based assessments of trends in entrepreneurial and innovation indicators and policies. (see e.g. Waasdorp (2002) Stevenson (2002)).

These analyses reveal a holistic[3] approach to entrepreneurship and innovation policy in the Netherlands. It encompasses both policies aimed at individuals and attitudes, as well as policies aimed at companies and organisations in the public and private sectors. They also reveal that many of the conditions that are thought to be necessary for high levels of innovative entrepreneurship based on technology transfer are now in place.

Furthermore, on many relevant dimensions the Dutch economy benchmarks well against other EU economies. This includes, in particular, relatively high levels of public R&D expenditure, of patenting, and of scientific output, relatively positive nascent entrepreneurs' attitude to failure, as well as relatively high levels of equity and venture capital, and of innovative output. The Netherlands, moreover, scores well in terms of the Global Entrepreneurship Monitor (GEM) survey and interview-based assessments of the business climate for entrepreneurship. The same source suggests that entrepreneurial activity has held up relatively well in the Netherlands in the face of the global macroeconomic slowdown[4].

Some evidence, however, points to concerns about technology transfer issues. Thus there is some evidence that in terms of human capital provision, the proportion of new science and engineering graduates per 1,000 of the population is half that of the EU average and employment in high-tech and medium-tech manufacturing and high-tech services is below average, and about average, respectively compared to the EU (EU 2001). Lack of skilled labour is also identified in recent surveys as the major constraint for SMEs forcing them to rely on internal training Bosma (2003). Lack of marketing and management skills are also emphasised as spin-off constraints in recent research (Kreijen and van der Laag (2003). There is also some evidence that new start-ups in high growth sectors are relatively low by international standards (EIM (2001)).

The GEM survey and interview programme produces some further recent results bearing on technology transfer. The GEM surveys for 2002 show that on average 3.5% of GEM key informants across their global sample of countries perceive knowledge transfer to be a weakness in the promotion of innovative activity amongst new and start-up firms, whereas 15% of key informants in the Netherlands do (Muizer (2003) p.6). Similar evidence also raises concerns about equal access to, the cost of, and value of subsidies for technology transfer from public research centres and universities to new and growing firms in the Netherlands. Some concern is also expressed about the capacity to support world-class technology in at least one area. This evidence is primarily based upon attitudinal surveys of expert practitioners carried out as part of the GEM programme for 2001.

It is worth noting that the differences with respect to the average scores on these issues for the EU countries are very small. The concern is more based on the scores given for this aspect of Dutch policy *relative to other Dutch policy scores.* (See e.g. Bosma, Stigter and Wennekers (2002) esp. Table 7 p.42). Moreover other surveys paint a somewhat different picture. Thus the findings of the EU innovation barometer for 2001 show the Netherlands with one of the highest proportions of firms reporting satisfaction with access to advanced technologies. It also shows Dutch firms as third most likely to collaborate with universities and to report the highest propensity to use intellectual property licensing as a means of accessing advanced technology (EU (2002)). Since the barometer survey excludes firms with less than 20 employees this suggests that such difficulties as have been identified may be size-specific rather than general across the SME spectrum.

Finally Marcel Kreijen and Astrid van der Laag (2003) present recent benchmarking evidence on university spin-offs, which confirms the relatively low numbers of such activity across all countries and shows a small gap (in terms of average numbers of spin-offs per university year) between the Netherlands (6.4) and the international benchmark group (7.1). They argue that Dutch research institutions face constraints in developing spin-offs arising from shortages of start-up capital, and lack of physical space and of internal expertise to support spin-offs. They also stress the need for management and marketing competence in spin-off development. Finally they emphasise the absence of an 'entrepreneurial culture' and tensions between the commercialisation of knowledge and 'the officially assigned task' of universities.

This may lead to perceived conflicts of interest as emphasised in Muizer (2003). He locates the root of those difficulties which do arise in '…an attitudinal problem of the ones who possess the knowledge', and argues that 'A conflict of interests seems to be the main cause for the poor interaction between public knowledge institutions and companies' and that this relates to a number of significant underlying causes. The first of these is identified as a conflict between the interest of scientists in autonomy in their pursuit of long-term fundamental, or basic curiosity driven research and the pursuit of directed short-term demand driven research for use in industry. Second, a tension is identified between the desire to publish by scientists and the need for commercial exploitation based on exclusivity. Finally, it is argued that scientists place too much reliance on contacts with large as opposed to small firms in forging relationships and, as a result, there is a complementary lack of emphasis upon spin-offs and start-ups.

Several policy approaches for the Netherlands have recently been suggested to resolve these problems. Thus Kreijen and van der Laag (2003) outline a new streamlined TechnoPartner strategy designed to raise the quality rather than the quantity of spin-offs, to use the education system to change culture, and to introduce the utilisation of research as a criterion when programming scientific research. Specifically policies are discussed based on seed corn funding for spin-off business plan writing and prototyping; state funded guarantees for seed-phase informal and formal venture capital spin-off investment; business plan competitions and advice for institutions and individuals on start up activities. This will be combined with a patent fund to subsidise university patent management, and a programme to strengthen the incubator network in which access to subsidy is linked to curriculum development. Regional incubators will be the principal instrument for delivering the coaching and networking structures around institutions. They anticipate that this 'is likely to lead in the short-term to a substantial strengthening of the Dutch economy on the one hand and improvement of the competitive position of the Dutch research institutions on the other'. The way in which research programming will be affected by considerations of usefulness is not spelled out but must be an important issue, given the claimed tensions between the needs of commerce and scientists. Indeed in Muizer's view attitudes are the central problem. 'The real solution therefore lies in the realisation of a change of attitudes' (Muizer (2003)).

I will return to the issue of the likely short-term impact of spin-off policies generally, and the nature of attitudinal conflicts and their resolution after discussing in turn the characteristics of recent US economic growth, the relative role of start-ups exit and entry in productivity growth and the nature of university industry relationships in the USA.

In analysing university/industry links in the USA I will emphasise that a linear view of knowledge transfer, in which there is an essentially sequential process running from basic research through development to commercialization, is fundamentally misleading. It leads too easily to a sense of a zero sum game in which to favour basic science is to prejudice commercialization. It leads to an overemphasis on apparently tangible commercial interactions based on new business formation at the expense of other critical interactions with existing firms, through publications, shared laboratory space, consultancy, and most fundamentally the education and training of high quality graduates and doctoral students. As Kreijen and van der Laag (2003) note, spin-offs need to be seen in perspective, as one aspect of a multi-faceted integrated approach.

3. High Technology, Productivity and GDP Growth: Arkansas v. Silicon Valley

European policy concerns with the link between the science base, technology transfer, and entrepreneurship developments have been given particular impetus by the transformation of the relative growth and productivity performance of the US economy compared to the EU and

OECD countries in the last decades of the 20th century. Particular emphasis has been placed here on the role attributed to technology based sectors in that transformation[5].

A few salient facts may illustrate the kind of data upon which these emphases are based. Between 1990 and 2000 the US economy grew at an annual average rate of 3.2%, compared with 2.0% for the EU 15 and 2.5% for the OECD 24 (OECD 2003). This was based upon faster productivity growth, which in contrast to the EU was combined with increased employment. By the turn of the last century high-tech value added as a proportion of manufacturing was 25.8% in the USA compared with an EU mean of 8.2% and the highest EU proportion of around 20% for Ireland (EU 2001).

It is worth looking at this performance more closely however. A number of studies have revealed that the role of technology *using* sectors, and innovation in organisational and management techniques bear as close attention as the performance of the high technology generating sectors. A recent analysis by Robert Solow is instructive in this respect (www.cmi.cam.ac.uk/ncn/summit-2001-videos/solow/text.html). Solow points out that US growth in the nineteen nineties was dominated by events from 1995. Whereas real GDP growth per person hour was 2.9% from 1947-1972, and 1.4 % from 1972-1995, it was 2.5% from 1995-2000[6]. Thus the recent US performance in this respect is essentially a return to very long run trends.

Above trend performance is focussed on a very short period (see also more generally on this point OECD (2003)). This should lead to some caution in attributing superior US performance in the second half of the nineties to specific cultural factors that might be expected to operate over longer periods of time such as a culture of enterprise, or attitudes to failure, or of small firm employment creation (which clearly predates this macroeconomic performance shift). It is also instructive to look more closely at the sectoral patterns behind the shift in growth performance to examine the role of technology based sectors in the 1995-2000 resurgence.

The contribution that a sector makes in an accounting sense to overall productivity and output growth depends on its productivity increase *and* its employment size. The significance of a sector in employment terms affects the weight that its performance has in affecting overall economy performance. Solow disaggregates US real productivity growth 1995-2000 between 59 sectors and shows that 6 of the 59 account for *all* of the acceleration in productivity growth. The net contribution of the other 56 was zero.

The top three were wholesaling, retailing, and security and commodity broking. The next three were electronic and electric equipment (semi-conductors) industrial machinery and equipment (computers) and telecoms. These latter three high-tech producing sectors contributed one third of the impact of the top three 'low tech sectors'. From this perspective it is clear that the superior performance was not accounted for by developments in the high technology producing sectors *per se*. High-tech sectors to be sure had high levels of productivity growth and this accelerated in the late nineties but their relative size meant they played a smaller role in macro performance than is often claimed (OECD (2003)). From a knowledge transfer policy perspective this means that attention should be paid to the processes affecting productivity change in technology using as well as technology producing sectors.

It is worthwhile, therefore, to look at the productivity dynamic that occurred in the lead sectors of wholesaling and retailing. In wholesaling, warehouse centralization and automation were based on 'old' IT. Scale gains and functional reorganisation were exploited in the face of competitive pressures from retailers. This was the so-called 'Wal-Mart effect'. Based on an Arkansas family start-up Wal-Mart's Market Share in retailing in the US in 1987 was 9%, with a productivity advantage of 40% over its rivals. By the mid-nineties its share was 40%. From 1995-1999 competitors raised productivity by 28% but Wal-Mart's productivity advantage rose to 48% (M.Schrage *Technology Review* March 2002 p.21). Its retailing productivity growth was based on scale effects in warehousing, electronic data interchange and bar code scanning. Productivity in the sector as a whole was driven by imitation, adaptation and organizational innovation by rivals.

From this perspective Arkansas made a greater contribution to productivity growth than Silicon Valley, and organizational and management innovation, as much as technological change, drove the productivity dynamic. However, this is not really the most important point. The key lesson to be drawn is more general. Wholesaling retailing and financial trading are all sectors that use information technology developments. ITC users are more significant than producers in 'accounting' for productivity growth but they depend upon the former for their innovative inputs. The effective use of those inputs requires organizational innovation and embodiment of ICT innovations in user sectors. The demand for, and capacity to absorb, the output of high-tech producing sectors by technology users are crucial drivers of overall recent US performance, and the latter sectors have supplied the products with high and rising efficiency. Thus investment in ICT goods and software is estimated to have accounted for 0.9 percentage points of US GDP growth 1995-2000 (OECD (2003) p. 46). The ability to absorb and benefit from this investment depended upon the technical competence of management in recognising and implementing appropriate technologies. A supply push technology transfer policy (focussing on output and business formation in high-tech sectors) that neglects the importance of the management and technical competence of the firms on the demand side (domestic users) will be missing an important lesson. This lesson is that investment in physical and software capital *and* investment in human capital and managerial and technical skills are required. It points therefore to a broader educational, curriculum and training side of technology transfer policy for innovative start-ups, and for technology users.

4. Entrepreneurship, New Firms and Economic Growth: New Boys on the Block versus Golden Oldies

In contrast to the policy emphasis placed upon entrepreneurship, it is a striking feature of the macro-economic literature on the determinants of differences in economic growth that it very rarely mentions entrepreneurship per se. It is also a pervasive problem of the literature on the determinants of economic growth that there are so many potential explanatory variables, and so many missing data problems, that systematic analysis comparing alternative explanations is difficult to achieve. Thus Freeman (2001) points out that in one influential review 87 different explanatory variables are reported for testing on cross section samples of long term growth rates for around 20 OECD countries.

In the case of adding entrepreneurship as yet another variable one key problem is how to define and measure it. Another is dealing with problems of causation. Are time series and cross section fluctuations in small business formation and growth a cause, or a consequence, of variations in economic growth over time, or across countries? Direct measures of entrepreneurial attitudes and activity have recently been developed as part of the GEM surveys. Development of better longitudinal datasets, of more direct measures of different entrepreneurial activity of this kind, may assist in econometric analysis of impacts on growth. Preliminary results along these lines reported in GEM (2002), however, reveal few systematic connections between entrepreneurial activity, entrepreneurial potential, or supporting framework conditions and growth (see esp. GEM (2002) p. 23 ff.). The GEM analyses are of necessity restricted to short periods and the authors acknowledge that more work needs to be done. A number of other studies have sought to link proxies for entrepreneurship, such as small business shares, or self employment, to cross national variations in growth or unemployment rates and report positive links or links which imply adverse growth consequences if these proxies depart from estimated equilibrium levels (see e.g. Caree et al (2002), Audretsch and Thurik (2002))[7]. It is also possible to draw some broad conclusions about the significance of entrepreneurial entry for productivity growth using a recent programme of comparative international research carried out by OECD (OECD (2003)). This decomposes productivity growth over time for a country into effects due to new entry, exit, and the performance of survivors, respectively. The analysis covers the largest OECD economies for the periods 1987-92 and 1992-97.

Productivity growth in any period for a national population of firms can be decomposed into: productivity growth within firms that survive; reallocation of output between high and low productivity firms that survive; the impact of new entry; and the impact of exit. The research shows that these components vary across countries and industries but that the dominant component in labour productivity growth in manufacturing[8] is that which is driven by survivors, i.e. 'golden oldies' with high 'within firm' productivity growth. Thus the 'within firm' shares ranged between 55% and 95% in the eighties/nineties, with France, Germany and the USA showing the highest shares for this component. Exit and entry are highly correlated across industries within countries, and the *net* effect of this 'churning' accounts for 20%-40% of labour productivity growth. The rate of churning is similar across the USA and the European countries. The net effect of churning is, however, dominated by the *exit* of low labour productivity firms rather than by new entry. Reallocation of activity amongst existing firms is usually less important than the other three forces.

New entrants, the 'new kids on the block', come and go with much less impact on productivity than improvements in 'golden oldies'. On average in the OECD sample about 20% of firms in any year are new but only 40-50% survives for 7 years. Moreover, entry frequently has a *negative* direct effect. The negative effect of entry arises essentially from the low productivity performance of new firms compared with incumbents. A positive new entry impact is unusual with Netherlands and Italy notable in this respect. Most strikingly the new entry component for the United States is large and *negative*, and the 'new kids on the block' are smaller *relative to the mean size of incumbents*. Moreover their survival rates appear to be lower. On the other hand those that survive grow faster in the USA than in Europe.

A number of other results are worth noting. First, new entry effects are bigger when productivity is measured over longer time periods, consistent with positive learning and scale effects as the new kids who stick around expand. Second, entry effects are bigger in information and communication technology sectors, in both manufacturing and services, where rapid technical change and relatively low entry barriers allow for a more dynamic entry regime[9].

This analysis has a couple of important implications for knowledge transfer policy linked to entrepreneurship. The first of these is that it is not entry *per se* but the *subsequent* survival and competitive expansion of new entrants that is important. A focus on barriers to post-entry growth is therefore as important as, or more important than, the generation of more new entrants, as such, in designing technology transfer and innovative start-up policy. Identifying and overcoming barriers to growth in productivity in incumbents is also important and will carry greater weight in industry productivity growth, not least because of their greater share of activity. Bridging gaps between incumbent firms, large and small, and the science base (i.e. the stock) yields potentially wider gains than focussing only on building new bridges through start-ups (i.e. the flow).

The second broad lesson is that prospects for innovative new entry may be sector/technology specific and be stronger the longer the period they have to work themselves out. It follows that some sector differentiation in policy is required. New entry plays a more positive role in high-tech sectors and over longer periods. Superior performance through innovative new entry requires patience and is a long game. Moreover, in so far as new firm entry is connected with innovation in new products and processes, it is important to emphasise that it is a highly skewed world. In the highly regarded UK government SMART (Small Firms Award for Research and Technology) scheme, 80% of sales generated by award winners were produced by the top 20% of award-holders. Equally, of the 20,968 active IPR licenses held by US universities that yielded $1.2billion of gross licensing revenues in fiscal year 2000 only 125 or 0.6% of the total generated more than $1 million each (AUTM (2002)).

There is, of course, a substantial literature on barriers to innovation in small and medium sized firms, which can shed some light on why success on average may be hindered, and on the relative role of access to the science base. It is important in interpreting it to note how constraints may be contingent upon macroeconomic conditions. Thus, for instance, perceptions of barriers in relation to access to finance, skilled labour, or export markets are sensitive to monetary policy, labour market conditions, and exchange rate movements. This is less likely to be a problem with the less contingent case of access to the science base. It is also important to note that whether access to technology is identified as a barrier may depend upon how options in survey questions are designed. Recent harmonised community innovation and other surveys have, however, asked directly about this issue and thus provide the opportunity to place some perspective on it in the EU.

The first thing to note is that these surveys show that universities and public research institutes rank well below customers and suppliers as direct sources of new technological knowledge for innovation in innovating firms especially at the lower end of the size spectrum (Cosh and Hughes (2001) EU (2002)). The second point to note is that access to new technology *per se* ranks systematically lower than other constraints on innovation. Thus the EU-wide results from the 2nd Harmonised EU Community Innovation Survey reported that SMEs experiencing constraints were more likely than large innovative enterprises to cite high innovation costs, difficulties of access to finance and the cost of compliance with regulation as the principal factors holding back innovation projects. Moreover, over 2/3 of EU SMEs cited skill shortages as an innovation problem (Cosh and Hughes (2001))[10].

In the EU innovation barometer survey firms in all countries except the Netherlands cited human resources as the main unsatisfied need for innovation (EU (2002). Similar patterns emerge from the regular panel survey of the UK SME sector carried out by my colleagues at the Centre for Business Research (CBR) in Cambridge covering the period 1991 to 2002. In the UK case high-tech firms and innovators were generally more likely than conventional and non-innovating firms to feel constrained by a lack of management, marketing, and sales skills. The effect was especially noticeable in high-tech and innovative service firms (Cosh and Hughes (1996) (1998) (2000)). This strongly suggests that a policy focus on technology transfer needs to be embedded in a wider framework. That wider framework must address the capacity of firms that are encouraged to engage in knowledge transfer to be properly able to absorb, implement and exploit that knowledge and employ appropriately qualified staff.

5. Industrializing Knowledge, Spin-outs and Attitudes at the University-Industry Interface: the USA and Pasteur's Quadrant

The increasing role of public sector science in industrial development can be readily illustrated. In the late 1990's it has been estimated that over 75% of references to scientific publications in US patent applications were to publicly funded science. Moreover the average number of US scientific papers cited in US patent applications rose more than six-fold between 1985 and 1998. The rise was particularly striking in biochemistry, organic chemistry, and medical and veterinary science (OECD (2002)). Finally, in 2000 over 450 companies based upon a university-licensed scientific discovery were formed in the USA, with over 80% of these founded in the state/province of the academic institution that created the technology. (OECD (2002), AUTM (2002)).

The growth and productivity performance of the USA, the dynamism of its high-tech sectors, and the translation of that into inputs for transforming the performance of the high-tech using sectors has led to great interest in the links between the science base and industry in that country. Perhaps most strikingly in the case of the UK a policy experiment is in progress in which the government is funding a joint venture between the University of Cambridge and MIT specifically designed to develop and transfer aspects of US practice in university-industry collaboration into a UK context (http://www.cambridge-mit.org). It is worthwhile, therefore, looking at the situation in the USA, to see the extent to which it has been successful in addressing attitudinal and incentive issues and the policy implications that may be drawn.

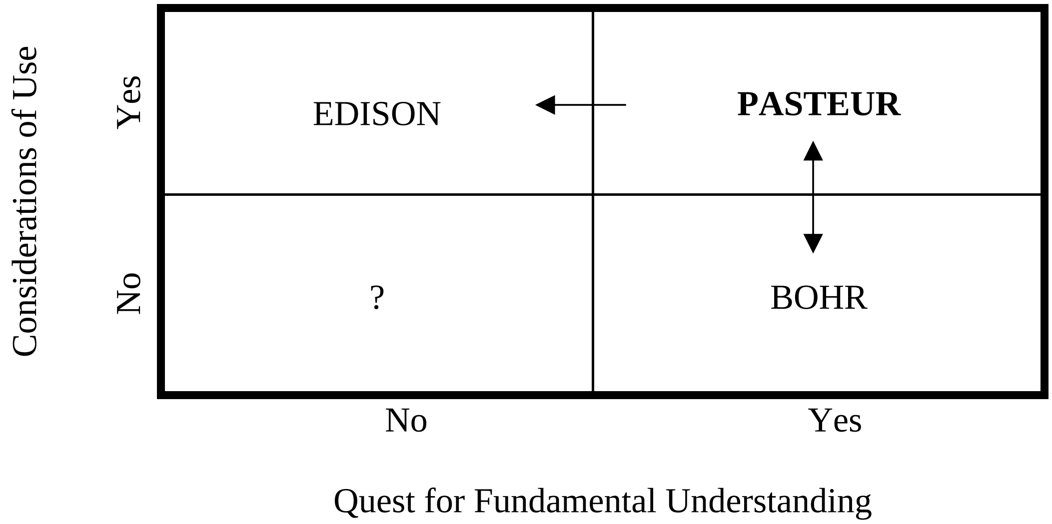
One of the most influential views of the nature of science-industry relationships in the U.S. in the post-second world-war period was set out by Vannevar Bush. Bush (Director of the war-time Office of Scientific Research and Development) in his report to the U.S. president proposed a strategy for US science-industry relations after the war which would both ensure substantial government resourcing for basic science and, at the same time, free basic science from government direction (Bush (1960)). Bush's view was that national competitiveness would suffer if basic science was neglected because depending upon other countries for these advances would slow down US industrial progress. The assumptions behind his proposals to avoid this happening to the US have been succinctly summarised in Stokes (1997). In Bush's own words these were that 'basic research is performed without thought of practical ends' and that 'applied research invariably drives out pure' if they are mixed.

On the other hand 'basic research is the pacemaker of technological progress'. Leave basic science to pursue its own agenda and, as Stokes puts it, it 'will be a remote but powerful dynamo' as applied research and development will convert discoveries into useful applications (Stokes (1997) p.3). The 'technology transfer problem' on this view becomes one of defining appropriate institutions and incentive structures for stages along an essentially linear path from basic research through applied research, and then through development and into production. Research is either basic or applied and a move towards one type means a move away from the other. Equally an emphasis in policy to emphasise *use* in funding strategies implies an interference with the curiosity-driven pursuit of fundamental understanding of the basic research scientist. The potential conflicts of interest between the needs of research users and those involved in basic research can then be seen as the manifestation of this separation.

It has however been persuasively argued that this approach misunderstands the actual pattern of research activities. In particular it has been argued that a substantial proportion of university and publicly funded research has always combined both considerations of use and the pursuit of fundamental understanding. As a result the dichotomous approach in the linear model is misleading, both in terms of science practice and in terms of policy design. This view has been captured in the quadrant diagram shown in Fig.1 due to Stokes (1997). Here a distinction is drawn between research that is solely concerned with use, typified by the work of Edison, research that is solely concerned with fundamental understanding typified by the work of Bohr, and research that involves both, typified by Pasteur, which Stokes demonstrates has a long and distinguished role in the research structure of the natural sciences[11].

Seen from this perspective the problem for technology transfer policy can be perceived as having three broad components. The first is how to encourage recognition of the importance of Pasteur’s quadrant in scientific and policy discourse. The second is how to promote/support activity in Pasteur’s Quadrant by enabling scientific recognition of society’s concerns with particular areas of use as a stimulus for the pursuit of fundamental understanding in relevant areas. The third is how to encourage communication and interaction between quadrant communities. On this interpretation the success of the USA in industrializing knowledge is to be understood less in terms of specific policy initiatives to transform basic into applied research but in the ability of its university system to populate all boxes and enable interaction across them.

Figure 1. Pasteur's Quadrant



Source: Stokes (1997)

This ability has, in turn, been the result of the decentralized, competitive and regional structure of the system and its close coupling of research and graduate education. Moreover, the second world-war and the cold-war led to a massive expansion in federally funded scientific research in universities linking fundamental knowledge to potential use. These characteristics have led to historically diverse streams of funding, including high levels of industry funding, and a close relationship of universities with state and regional industrial research needs, most notably linked to the general origins and mission of land grant universities. The integration of graduate education with research has also led to the argument that the primary contribution of US universities to technological innovation is the human capital it produces. (See Branscomb et al (1999), Rosenberg and Nelson (1994), Feller (1999), Etzkowitz, (1999), Stokes (1999), Tornatzky Waugaman and Gray (2002) and National Association of State Universities and Land Grant Colleges (2002) for an overview of relevant evidence on these points).

These longstanding tendencies have received added impetus in the last quarter of the 20th century from a series of policy initiatives concerned with raising competitiveness in the face of international, and especially Japanese, competition. These have included relaxation of anti-trust laws to enable research joint venture collaborations (e.g. the 1984 National Cooperative Research Act), policies to promote research on generic technologies (e.g. the Advanced Technology Program established via the 1988 Omnibus Trade and Competitiveness Act, which by 2000 had 57% of its projects with university participation[12]), increased National Science Foundation funding for University Industry Research Centres, and the introduction of the Small

Business Innovation Research Program. The latter mandates federal agencies to allocate around 4% of their spending to small innovative businesses and has had close connections with many university related spin-outs. There has also been a series of court decisions strengthening intellectual property rights and the passing of the Bayh-Dole Patent and Trademarks Amendment Act 1980. The Bayh-Dole Act gave blanket permission for performers of federally funded research, including universities, to file for patents and grant licenses, including exclusive licenses, on the basis of them. Its purpose was to accelerate the commercialization of publicly funded R&D (on these developments generally see e.g. Branscomb et al (1999), Cohen et al (1998), Poyago et al (2003), Mowery et al (1999), Wessner (2001)).

These developments were associated with a surge in university patenting and licensing activity, which coincided with the development in biomedical and biotechnological sectors that were naturally encouraging to closer scientific industry relationships[13]. The ratio of university based patents to university R&D spend doubled from 1975-1990, and the top 100 research universities doubled their number of patents between 1979 and 1984, and again between 1984 and 1989. There was an explosion in the numbers of university licensing offices from 25 in 1980 to 200 in 1990 (Mowery et al (1999)). The number of US patent applications filed by respondents to the annual surveys carried out by the Association of University Technology Managers (AUTM) rose from 2,469 in 1991 to 9,925 in 2000, and licenses and options executed rose from 1,278 to 4,362 over the same period, accompanied by a rise in gross license income from $186 million to $1263 million. The vast majority of the licenses yielding this income were exclusive. Even so by 1999 total gross licensing income was only around 2.7% of the total R&D expenditure by universities.

In the context of arguments that European universities may attract substantial sums of further research funding from this licensing income it is important to note the latter finding. This caution is reinforced by recalling the skewness of the returns to spin-outs and licensing, and the low likelihood of many universities making a major breakthrough from this type of funding (AUTM (2000)). The associated costs of staffing and administering technology licensing and related offices to the degree required mean that very small net income or 'net losses' can frequently occur, and where substantial sums do arrive they are associated with one or two big hits (Mowery and Sampat (2001) Trune and Gosling (1998)).

In the context of arguments emphasising the importance of licensing and spin-offs as a means of transferring knowledge it is also important to note that patenting remains significantly less important than other means of knowledge transfer. Thus in the view of leading scientists at MIT patenting accounts for less than 10% of knowledge transferred and exchanged from their labs and ranks well below graduate recruitment, consultancy and publication. This ordering of importance is shared by industry and other universities (Cohen et al (1998), Agrawal and Henderson (2002), Lester (2003)) and it underscores the importance of widespread personal and corporate interactions in facilitating knowledge transfer. Nor are spin-offs the most significant component of licensing activity. This is illustrated next by examining the relative role of innovative start-ups, existing small firms (with less than 500 employees), and existing large firms in US university licensing and spin-out activity. In doing this it is important to note that by statute licensors of inventions made with federal funding must show a preference for small companies.

It has been estimated that AUTM licensing activity was associated with 3,376 new start-ups between 1980 and 2000, of which 2,309 were still operational in the latter year[14]. The number of such start-ups doubled between 1994 and 2000. In 2000 618 licenses were granted by universities, hospitals and research institutes to start-ups, 2002 to small firms and 1,346 to large firms. Thus 51% of licenses granted were to small companies, and only 15% were to start-ups. Over 90% of the start-up licenses were exclusive, as were 42% of those granted to small firms, compared to 37% for large firms (AUTM (2002). In 2000 around 56% of the 454 start-ups which were reported also had an equity stake held by the university.

Given the size of the US business population and the total number of start-ups (circa 500,000 per year), even in high-tech sectors, university start-ups are small in number. Moreover, start-ups are a minority within overall licensing activity. This general finding is true for the OECD as a whole (OECD (2001b)). However, the AUTM approach employs a conservative definition of a university start-up and ignores start-ups by alumni, or former students who deploy their human and intellectual capital in business start-ups not specifically linked to university patents. It is also important to note that an emphasis on start-ups also ignores the role that universities play more generally in terms of consultancy contracts, the provision of qualified graduates and postgraduates as employees for existing businesses, and as progenitors of businesses unconnected with university licensed activity (Branscomb et al (1999)).

It is, nevertheless, of interest to ask which features lead to success in spin-off generation at the university level[15]. In doing this it is important to recognise that indicators of success in this area are not well defined. The number of spin-outs alone is insufficient because it neglects their initial scale as well as subsequent growth and survival. Equally the skewness of outcomes means that a portfolio approach to evaluation is necessary. Finally, even if relatively few spin-outs grow significantly, they can play an important transfer role through specialist consultancy (Keeble et al (2001), OECD (2001)). There is clearly room for much more careful work here, nevertheless a number of interesting results have emerged.

It appears that strong local *formal* venture capital markets and university based venture capital funds are not closely linked to spin-off formation and performance whilst more early stage *informal* venture capital may be more relevant. This may reflect in the first case the preference of the formal market for later stage investments, and in the latter case the need to ensure that the funds have clear and stable goals and adequately incentivized management (Di Grigorio and Shane (2003), Lerner (1999)).

A clearly articulated and well understood university policy on licensing and IPR is also positively linked to spin-off generation. It also helps in the promotion of common understanding of its role in university activity (Di Grigorio and Shane (2003), Siegel et al (2001) and for the UK Lockett et al (2003)). The same is true of the extent to which licensing is combined with well managed equity support in early stage development of the spin-off. This helps address cash flow, licensing patenting and agency costs (Hsu and Bernstein (1997)).

There is also evidence that spin-off activity is negatively related to the share of inventor royalties compared to industry licensees, and positively related to total industry spend on university-based research (Di Grigorio and Shane (2003)). Above all intellectual eminence and star status matter, and only big research universities can justify serious investments in spin-off support activity (see e.g. for the OECD, OECD (2001) and for Japan, Zucker and Darby (1998)). Moreover, there appears to be a clear negative link between university research intensity and eminence, and the *relative* degree of involvement with local or regional development activity and smaller firms (for the UK see for example HEFCE (2003)). Moreover the contribution which spin-offs and industry university interaction can make locally or regionally is the result of a very long game (Link and Scott (2003)). It is also closely related to local or regional absorptive capacity. Spin-off push on its own is not enough (see for example Florida and Cohen (1999), and Fogarty and Sinha (1999)).

Finally, it is important to note that tensions continue to arise in the USA between competing conceptions of the virtues of openness in science discourse, and the apparent and real restrictions on scientific discourse which exclusivity in licensing patenting and spin-offs can produce. Tension also arises from the impact such activities can have on the direction of research activity. These tensions, of course, lie at the heart of many of the attitudinal issues raised by Muizer. Here there are relatively few research findings and the jury is still out. Much work remains to be done. Mowery et al (1999) in their detailed case study could find few direct indications of changes in research direction, whilst Louis et al (2001) and Blumenthal et al (1996) report greater secrecy and less disclosure over research findings amongst industry funded researchers. It does not appear, however, that such researchers are any less productive scientifically as judged by peer review (see e.g. Zucker and Darby (1996) and the evidence reviewed in Poyogo-Theotoky et al (2003)). This is consistent with the role played by research in Pasteur's quadrant. It could also reflect some selection bias in that the best scientists have the greatest opportunities to attract industrial support.

6. Concluding Remarks

This brief set of reflections has been intended to place innovative start-ups and university spin-off activity in perspective and draw some possible policy implications.

I have discussed evidence from a range of countries but have placed some emphasis on the USA. This was deliberate because there is little doubt that the experience of that country has loomed large in many policy discussions about the competitive challenges and policy options facing the EU and its member states. This is not to deny that a great deal can be learned from the sharing of best practice in the EU and the analysis of other country specific innovation systems. Indeed the discussion of the experience of the USA points to many issues (e.g. the scale of federal support, and the nature of the university system) which should caution against the notion of transplanting parts of any one system onto another.

That said, the first general point that should be made is that an emphasis on technology-based industries as conventionally defined ignores the critical role played by technology 'using' industries. Economy level impacts of developments in a sector depend upon the size of the industries affected and not just their productivity growth. This is exemplified by the role of the wholesaling and retailing sectors in the USA.

The second general point is that a key driver of overall productivity growth is productivity growth in existing firms. The direct effect of new entry is considerably smaller, and university based spin-offs are a tiny proportion of overall start-ups. The impact of new entry is greater over the longer term and plays a bigger role in more technologically turbulent industrial settings.

These two general points suggest that raising the rate of innovative university spin-offs is unlikely by itself to lead to major short-term shifts in macroeconomic performance. Moreover, the direct impact through the growth of such firms and the indirect effect they may have on technology using sectors depends critically upon management competence and organisational innovation. This points to the development of educational programmes in business schools which combine technical with managerial competence, and mobility of experienced managers across size classes of firms. Whether these should be characterised as courses in *entrepreneurial skills* is a moot point since they are in essence generic management and business skills applied in particular industrial and business settings.

The third general point is that the notion of knowledge transfer as a linear process whereby basic science in pursuit of fundamental understanding has to be dragged through successive stages to considerations of use is deeply misleading. It ignores the many mechanisms whereby issues of use and fundamental understanding are jointly considered. It can also lead to too narrow a focus on 'commercialization' through patenting and spin-offs as the final stage compared to the many other dimensions of interaction through publication, consultancy and graduate education and recruitment.

On the more specific issue of the process of university-industry interactions it is helpful to break away from the linear approach and to summarize the implications of the knowledge transfer process in the USA in terms of the interactions produced, the incentives to take part which are provided, and the institutional arrangements or structures in which they occur (see e.g. OECD (2002)).

In institutional terms it is clear that the diverse decentralized and regional structure of the US university system has played a central role in enabling university/industry interactions and the populating of Pasteur's quadrant. This has, however, occurred over a very long period of time. It is also the case that the scope for other countries to follow this path depends upon the structure of their own educational systems. The proposed attention to be paid in the new Dutch approach to the costs of patent management and the need to develop explicit rules of the game and clear expectations about commercialization are important in this respect. The impact of this 'push' aspect of policy will however depend upon the absorptive capacity of the firms (existing and potential) and regions at which it is targeted. This is especially so given the correct emphasis to be placed upon quality rather than quantity of spin-off activity. It will also depend on the capacity to develop, in pace with the policy, a pool of suitably skilled and incentivized professionals to staff the activities. Developing university/industry interactions is a long game, and is not an area where policy should be expected to deliver short-term payoffs.

The sheer scale of US federal expenditures, and the capacity to use that to drive programs to include start-up and SME involvement, has had a powerful incentive impact upon the involvement of these groups in technology transfer. The creation through public funds of research institutions specifically developing university-industry relations has also been a significant force. This points to the creative use of public expenditure programs to act as a powerful pull-through agent so that a high public R&D spend and a high share of public expenditure in GDP offer major opportunities for such activity (see also Metcalfe et al (2003) on this point). Mandating a proportion of such expenditures has clearly been an important component of the small high technology dynamic in the USA. It would be interesting to consider this aspect of policy further in the Dutch context given its relatively high share of public R&D expenditures.

Spin-outs are an important but small and variable part of the overall range of ways in which the industrialization of scientific advance can occur. The full benefits of universities in enhancing the opportunities for innovative start-ups, and the diffusion of innovation impacts through the economy, depends upon several dimensions of interaction. These include an engagement through the supply of a highly educated graduate labour force, as well as through the full range of dissemination activity including scientific publication, patents licensing and consultancy, and modes of cooperation including shared laboratory space, ‘user’ conferences and foresight exercises (Lester (2003)). Diffusion, moreover, depends upon absorptive capacity in firms and the ability of technology users to recognise and benefit from technological developments. Interactions with the stock of existing firms as well as the flow of new start-ups are essential.

Finally it is clear that some questions remain to be answered about the impact on the direction and quality of university research of including considerations of use as a criterion in deciding upon funding patterns. The central point, however, is that it is essential to encourage interactions between academia and industry which encourage the joint recognition of activity in Pasteur’s quadrant as satisfying both the search for fundamental understanding and its interplay with considerations of use. This requires a major commitment to the full range of university/industry dimensions along which knowledge transfer occurs. A perception that changing attitudes means a move by universities away from 'basic' to applied research focussed on the generation of patents, licensing income and spin-offs would be to reinforce an outmoded linear view of innovation. It will make the long road to an effective entrepreneurial society based on technological advances even longer and the outcome more uncertain.

Notes

1 As van der Laag and Kreijen (2003) point out there is considerable imprecision in the literature about the definition of, and use of the terms, university spin-off and university spin-out. Where a specific source referred to in this paper uses one of these terms I have tried to use the same nomenclature, and where a specific definition is relevant I spell it out (e.g. in relation to data on US spin-outs based on licensing university based technology). In general the terms spin-off and spin-out are used interchangeably in this paper.

2 For an overview of OECD spin-off activity see OECD (2001). Surveys of general university industry links in the UK are to be found in UNICO-NUBS (2002), CURDS (2001) and HEFCE (2003). EU (2002a) and UKBI (2000) and Clarysse et al (2002) provide a more normative assessment of good practice in spin-off and incubator management and design respectively. Siegel et al (2003) provide a concise overview of evaluations of the impact of science park location on business performance in the UK, (which is the most well developed country in this regard) and conclude equally concisely that 'The existing evidence suggests that the 'returns to location on a UK science park are negligible' (Siegel et al (2003) p.180). They urge further research. For an assessment of incubators and their impact in an American context producing equally insignificant results see Di Gregorio and Shane (2003).

3 It is of course easy for 'holistic' policies to become overlapping, inconsistent, and uncoordinated. In the UK a recent overview of enterprise support policy identified over 150 separate programmes that are to be consolidated into 15 or 16 new programmes. The intention in the Netherlands to consolidate spin-off support programmes in developing a new policy initiative based on the latest evidence as set out in van der Laag and Kreijen (2003) is therefore an excellent idea.

4 Thus the EU Innovation scoreboard for 2002 shows that in terms of the ratio of total R&D to GDP the Netherlands was at 1.92% just above the EU average of 1.85% in a group including Denmark, Belgium and the UK. It was just below average in terms of private business R&D. In terms of the ratio of public R&D expenditure to GDP however the Netherlands at 0.87% was matched only by Sweden and Finland in the EU and it outstripped both the USA and Japan. The harmonised community innovation survey also shows that

business innovation expenditures as a proportion of manufacturing sales were about average for the EU. The Netherlands was also the leading EU nation in terms of new capital raised in stock markets as a % of GDP and above average in terms of high-tech venture capital investment. The total of formal and informal venture capital as a % GDP in the Netherlands is second only to that of the USA amongst high GDP countries and only US and Sweden have more domestic venture capital funds but as with the UK this is focussed more on later stage and buy-outs than start-ups (Bosma (2003), EU (2001)).

Innovation output performance matches those input measures that were above average. Thus European Patent Office high-tech patent applications by the Netherlands at 35.8 per million of the population was second only to Finland in the EU and outstripped both the USA and Japan. The Netherlands also ranked third in the EU behind Finland and Sweden in terms of US patent office high-tech applications. In terms of innovative capacity the EU innovation surveys reveal that Dutch performance for small firms is above average and somewhat better relatively than performance for its medium and larger firms. Netherlands scientific and technical journal article production is above average, and above both UK and USA (Muizer (2003) and EU (2001)).

5 The role of clusters has also been emphasised for similar reasons. On the significance of clustering effects in economic growth and development see e.g. OECD (2001b), Porter and van Opstal (2001), and Porter and Ackerman (2001), and for a critical review of this literature as a guide to policy Martin and Sunley (2002). This general literature is not reviewed here although some attention is paid to the role of local spillovers in patterns of development in university-industry relationships.

6 The same picture of a concentrated period of growth in the second half of the nineties emerges if the period 1972 to 1995 is disaggregated and allowance made for the nature of the trade cycle (OECD 2003).

7 For example, Carree *et al* (2002) present a two-equation model to analyse the interrelationship between economy-wide business ownership rates and economic development. They apply the model to a data set of 23 OECD countries for the period 1976-96. Their entrepreneurship proxy is the business ownership rate, defined as the

number of non-agricultural business owners (both unincorporated and incorporated) as a share of the labour force (see Van Stel, 2003, for a description of the COMPENDIA (Comparative Entrepreneurship Data for International Analysis) dataset on which this analysis is based). In their paper, a hypothesized 'equilibrium' relationship between business ownership rate and stage of economic development (as proxied by GDP per capita) is estimated. They report a U-shaped relationship, which is negative for the larger part of the range of GDP per capita but with evidence of a positive relationship at the highest levels of GDP per capita. They also argue that countries that out-of-equilibrium level of business ownership had a negative impact on economic growth, but experienced slow convergence to 'equilibrium' ownership rate levels.

8 Similar results hold for services although measurement difficulties produce more variability across countries in the patterns observed (OECD (2003) p.136).

9 In a similar vein Bosma and Nieuwenhuijsen (2000), for example, assessed the impact of churning on total factor productivity growth on a regional basis for the Netherlands. They found a positive effect of 'churning' on total factor productivity growth for services industries, over a three-year time period, but no short-term impact in manufacturing industries.

10 It is important to note that there are some variations in the firm size cut-off points used by countries in carrying out the CIS surveys. Whereas some countries include all firms, others exclude firms with less than 10 or 20 employees. So the results for some countries will exclude constraints reported by the very smallest firms (see e.g. Cosh Hughes and Wood (1998)).

11 The fourth quadrant is left unlabelled by Stokes. It is not empty but contains research that for instance systematizes knowledge in an area (e.g. research producing ornithological field guides (Stokes (1997)).

12 See for example Hall et al (2001) and Wessner (1999) for analyses of the AT Program and Grossman et al (2001) for a wider evaluation of academic research impacts on industrial performance.

13 The precise role of Bayh-Dole in these trends is difficult to isolate because of the problem of establishing a good counterfactual.

Mowery et al in a detailed examination of the Universities of California, Columbia, and Stanford argue that the scale of existing university industry interaction had already led to licensing activity reinforced in biomedical areas by separate IPR court judgements (Mowery et al (1999)). Equally it can be argued that in one of the earliest most dynamic areas of patenting and licensing, (biotechnology) conditions were propitious for scientist entrepreneurs exercising intellectual ownership rights to exploit their discoveries because of their combined tacit and codified knowledge. In the early stages this ability rested with a small community of scholars who chose to stay with their academic institutions whilst developing the commercial possibilities of the science (Colyvas et al (2002), Zucker et al (1998), and Poyago-Theotoky et al (2003)).

14 The AUTM use a conservative definition of a university-based start-up, which specifies that the start-up must be dependent upon the license from the institution for its formation (AUTM (2002)). It should be noted that there is some upward bias in the data quoted here because of increases in the number of institutions responding to the AUTM surveys. The AUTM also report results for constant samples that show the same broad trends reported in the text.

15 There is a substantive literature on which types of firms or individuals succeed in spin-offs, which is not addressed here, see for example Shane and Stuart (2002), Levin and Stephan (1991), Roberts (1991), and Zucker et al (1998).

References

Agrawal, A. and Henderson R, (2002) "Putting patents in context", *Management Science*, January

Audretsch, D.B., Lehman, E.E. and Warning, S. (2003) 'University Spillovers: Strategic Location and New Firm Performance' *Centre for Economic Policy Research Discussion Paper* No 3837 March 34pp

Audretsch, D.B. and Thurik, R. (2002) 'Linking Entrepreneurship to Growth' *OECD STI Working Paper* 2081/2

AUTM (2002) *AUTM Licensing Survey: FY 2002 Survey Summary*. Northbrook Illinois

Blumenthal, D., Campbell, E.G., Anderson, M.S., Causino, N. and Louis, K.S. (1996) 'Withholding Research Results in Academic Life Science: Evidence from a National Survey of Faculty' *Journal of the American Medical Association* 277 (15) pp 1224-1228

Bosma, N.S., and H.R. Nieuwenhuijsen (2000), Turbulence and productivity in the Netherlands, *EIM Research Report* H199909, EIM: Zoetermeer

Bosma, N., Stigter, H., and Wennekers, S. (2002) *The Long Road to the Entrepreneurial Society. Global Entrepreneurship Monitor 2001 The Netherlands*. EIM Business and Policy Research March

Bosma, N (2003) 'Entrepreneurial Activity and Innovative Start-Ups' in van der Laag, A. and Snijder, J. (eds) *Entrepreneurship in the Netherlands: Knowledge Transfer, developing high-tech ventures.* Ministry of Economic Affairs and EIM Business and Policy Research, the Hague, the Netherlands

Branscomb, L.M., Kodama, F. and Florida, R (eds) (1999) *Industrializing Knowledge* MIT Press, Cambridge, Mass.

Bush,V. (1960) *Science- The Endless Frontier: A Report to the President on a Program for Post War Scientific Research.* National Science Foundation Washington D.C. (reprinted 1999)

Candell, A.B. and Jaffe,A.B.(1999) 'The Regional Economic Impact of Public Research funding: A Case Study of Massachusetts' in Branscomb, L., Kodama, F. and Florida, R. (eds.) *Industrializing Knowledge* The MIT Press, Boston, Mass.

Carree, M.A., A.J. van Stel, A.R. Thurik and A.R.M. Wennekers (2002), Economic Development and Business Ownership, *Small Business Economics* 19, 271-290

Clarysse, B., Lockett, A., Quince, T. and Van de Velde, E. (2002) *Spinning off new ventures: a typology of facilitating services* IWT-Observatory Brussels

Cohen, W.M., Randazzese, L., and Walsh, J. (1998) 'Industry and the Academe: Uneasy Partners in the Cause of Technological Advance' in Noll, R.G. (ed) *Challenges to Research Universities* Washington D.C., Brookings Institution Press

Colyvas, J., Crow, M., Gelijns, A., Mazzoleni, R., Nelson, R., Rosenberg, N. and Sampat, B. (2002) 'How do University Inventions get into Practice?' *Management Science* pp.1-12

Cosh, A.D. and Hughes, A. (eds.) (1996) *The Changing State of British Enterprise Growth, innovation and competitive Advantage in the small and medium sized enterprise sector 1994-97*, ESRC Centre for Business Research, Cambridge

Cosh, A.D. and Hughes, A. (eds.) (1998) *Enterprise Britain: growth, innovation and public policy in the small and medium sized enterprise sector 1994-97*, ESRC Centre for Business Research, Cambridge

Cosh, A.D. and Hughes, A. (eds.) (2000) *British enterprise in transition: growth innovation and public policy in the small and medium sized enterprise sector 1994-1999* ESRC Centre for Business Research, Cambridge

Cosh, A.D. and Hughes, A. (eds.) (2001) 'Innovation and R&D in SMEs' in *Enterprises in Europe A Sixth Report*. Eurostat, Luxembourg

Cosh, A.D., Hughes, A. and Wood, E. (1998) 'Innovation Surveys and Very Small Enterprises' *ESRC Centre for Business Research Working Paper* No.89 June

CURDS (2001*) Higher Education-Business Interaction Survey: A Report to the UK funding bodies (HEFCE, SHEFC, HEFCW and DEL) and the Office of Science and Technology* Centre for Urban and Regional Studies University of Newcastle upon Tyne, December

Di Gregorio, D. and Shane, S. (2003*)* 'Why do some universities generate more start ups than others' *Research Policy* 32 pp209-227

DTI, H.M. Treasury, DFES, (2002) *Investing in Innovation: A strategy for science engineering and technology*. London July

EC (2002) *University spin-outs in Europe – Overview and good practice.* Directorate General for Enterprise EUR 17046 Luxembourg

EIM (2001) *International Benchmark ondernemerschap* Zoetermeer.

Etzkowitz, H.(1999) 'Bridging the Gap: The Evolution of Industry University Links in the United States' in Branscomb, L., Kodama, F. and Florida, R. (eds.) *Industrializing Knowledge* The MIT Press, Boston, Mass.

EU (2001) *2001 Innovation Scoreboard* Commission Staff Working Paper SEC (2001) 1414 Brussels, September

EU (2002a) *University Spin-Outs in Europe- Overview and Good Practice* Directorate General for Enterprise EUR 17046 Luxembourg

EU (2002b) *Innobarometer2001* Directorate General for Enterprise EUR 17048 Luxembourg

Feller, I (1999) 'The American University System as a Performer of Basic and Applied Research' in Branscomb, L., Kodama, F. and Florida, R. (eds.) *Industrializing Knowledge* The MIT Press, Boston, Mass.

Florida, R. and Cohen, W.M. (1999) 'Engine or Infrastructure? The University Role in Economic Development' in Branscomb, L., Kodama, F. and Florida, R. (eds.) *Industrializing Knowledge* The MIT Press, Boston, Mass.

Fogarty, M.S. and Sinha, A.K. (1999) 'Why Older Regions Can't Generalize From Route 128 and Silicon Valley: University-Industry Relationships and Local Innovation Systems' in Branscomb, L., Kodama, F. and Florida, R. (eds.) *Industrializing Knowledge* The MIT Press, Boston, Mass.

Freeman, R. (2001) 'What does modern growth theory say about government policy towards growth' in H.M. Treasury *Economic Growth and Government Policy* London April

GEM (2002) *Global Entrepreneurship Monitor 2002 Executive Report* Babson College, London Business School, Ewing Marion Kauffman Foundation

Grossman, J.H., Morgan, R.P. and Reid, P.R. (2001) 'Contributions of Academic Research to Industrial Performance in Five Industry Sectors' *Journal of Technology Transfer* 26 (1-2), 143-152

Hall, B.H., Link, A.N. and Scott, J.T. (2001) 'Barriers Inhibiting Industry from Partnering with Universities: Evidence from the Advanced Technology Program' *Journal of Technology Transfer* 26 (1-2), 87-98

HEFCE (2003) *Higher Education-business interaction survey 2000-01* HEFCE London, March

HM Treasury (2002) *Enterprise Britain: a modern approach to meeting the enterprise challenge* November, London

Hughes, A. (2001) '*Innovation and business performance: small entrepreneurial firms in the UK' in* H.M. Treasury, *Economic Growth and Government Policy*. London

Hsu, D., and Bernstein, T., (1997) 'Managing the University Technology Licensing Process: Findings From Case Studies' *Journal of the Association of University Technology Managers* 9, 1-33

Jensen, R. and Thursby, M.C. (2001) 'Proofs and Prototypes for Sale: The Licensing of University Inventions' *American Economic Review* 91(1) pp 240-259

Keeble, D.E. and Wilkinson, F. (2000) *High Technology Clusters, Networking and Collective Learning in Europe* Ashgate, Aldershot.

Kreijen, M. and van der Laag, A. (2003) 'Spin-Offs as a bridge between two worlds; a policy perspective' in van der Laag, A. and Snijder, J. (eds) *Entrepreneurship in the Netherlands: Knowledge Transfer, developing high-tech ventures.* Ministry of Economic Affairs and EIM Business and Policy Research, the Hague, the Netherlands

Lerner, J. (1999) 'Venture Capital and the Commercialization of Academic Technology: Symbiosis and Paradox' in Branscomb, L., Kodama, F. and Florida, R. (eds.) *Industrializing Knowledge* The MIT Press, Boston, Mass.

Lester, R.K. (2003) 'Universities and Local Systems of Innovation: A Strategic Approach' Presentation at the *ESRC/CBR workshop on High-Tech Business: Clusters, Constraints, and Economic Development*, Robinson College Cambridge 28 May

Levin, S. and Stephan, P., (1991) 'Research Productivity Over the Life Cycle: Evidence for Academic Scientists.' *American Economic Review* 81(4) 114-132

Link, A. N. and Scott, J.T. (2003) 'The Growth of Research Triangle Park' *Small Business Economics* 20 pp167-175

Lockett, A., Wright, M. and Franklin, S. (2003) 'Technology Transfer and Universities Spin-Out Strategies' *Small Business Economics* 20 pp 185-200

Louis, K. S., Jones, L. M., Anderson, M.S., Blumenthal, D. and Campbell, E.G. (2001) 'Entrepreneurship Secrecy and Productivity: a comparison of Clinical and Non-Clinical Faculty' *Journal of Technology Transfer* 26 (3) pp 233-245

Martin, R. and Sunley, P. (2002). 'Deconstructing Clusters: Chaotic concept or Policy Panacea' *ESRC Centre for Business Research Working Paper* No 244 University of Cambridge

Metcalfe, J.S., Coombs, R., and Georghiou, L. (2003) "Developing Best Practice Technology Policy" Paper delivered at The 2nd CMI National Competitiveness Summit Greta George Street London November (http://www.cambridge-mit.org/cgi-bin/default.pl?SSSID=448)

Mowery, D.C., Nelson, R.R., Sampat, B.N. and Ziedonis, A.A. (1999) 'The Effects of the Bayh-Dole Act on U.S. Research and Technology' in Branscomb, L., Kodama, F. and Florida, R. (eds.) *Industrializing Knowledge* The MIT Press, Boston, Mass.

Mowery, D.C. and Sampat, (2001) 'Patenting and Licensing University Inventions: Lessons form the History of the Research Corporation' *Industrial and Corporate Change* 10 (2), pp. 317-355

Muizer, A (2003) 'Knowledge Transfer to Innovative Start-Ups' in van der Laag, A. and Snijder, J. (eds) *Entrepreneurship in the Netherlands: Knowledge Transfer, developing high-tech ventures.* Ministry of Economic Affairs and EIM Business and Policy Research, the Hague, the Netherlands

National Association of State Universities and Land Grant Colleges (2001) *Shaping the Future: The Economic Impact of Public Universities* Office of Public Affairs Washington D.C. August

OECD (2001a) *Science and Technology and Industry Outlook: Drivers of Growth-Information Technology, Innovation and Entrepreneurship* OECD Paris

OECD (2001b) *Innovative Clusters: Drivers of National Innovation Systems* OECD Paris

OECD (2001c) 'Fostering High-Tech Spin-Offs: A Public Strategy for Innovation' *OECD Science Technology Industry Review Special Issue* No 26, Paris

OECD (2002) *Benchmarking Industry Science Relationships* OECD Paris

OECD (2003) *The Sources of Economic Growth in OECD Countries.* OECD Paris

Porter, M.E. and van Opstal, D. (2001) *US Competitiveness 2001: Strengths Vulnerability and Long Term Priorities* US Council on Competitiveness, Washington

Porter, M.E. and Ackerman, F.D. (2001) *Regional Clusters of Innovation* US Council on Competitiveness, Washington

Poyago-Theotoky, J., Beath, J.,and Siegel, D.S.(2002) 'Universities and Fundamental Research: Reflections on the Growth of University-Industry Partnerships' *Oxford Review of Economic Policy,* Vol 18, No 1 Spring pp 10-21

Roberts, E. (1991) *Entrepreneurs in High Technology - Lessons from MIT and Beyond.* Oxford University Press, New York

Rosenberg, N. and Nelson, R.R. (1994) 'American Universities and Technical Advance in Industry' *Research Policy* 23. pp 323-348

Shane, S., and Stuart, T., (2002) 'Organizational Endowments and the Performance of University Start Ups' *Management Science* 48(1), 154-171

Siegel, D. S., Thursby, J.G., Thursby, M.C. and Ziedonis, A.A. (2001) 'Organizational Issues in University-Industry Technology Transfer: An Overview of the Symposium Issue', *Journal of Technology Transfer* 26, 5-11

Siegel, D.S., Westhead, P. and Wright, M (2003) 'Science Parks and the Performance of New Technology-Based Firms: A Review of Recent UK Evidence and an Agenda for Future Research' *Small Business Economics* 20 pp177-184

Stel, A.J. van (2003), *COMPENDIA 2000.2: a harmonized data set of business ownership rates in 23 OECD countries,* EIM Research Report 200302, Zoetermeer: EIM. http://www.eim.net/smartsite.dws?id=41&sooID=6&perID=265

Stephan, P.E. (2001) 'Educational Implication of University-Industry Technology Transfer' *Journal of Technology Transfer* 26(3) pp199-205

Stevenson, L. (2002) 'Innovation and Entrepreneurship: Dutch Policy in an International Context' in *Entrepreneurship in the Netherlands: Innovative Entrepreneurship. New Policy Challenges* EIM Business and Policy Research and Ministry of Economic Affairs February pp 43-86

Stokes, D.E. (1997) *Pasteur's Quadrant: Basic Science and Technological Innovation* Brookings Institution Press, Washington, D.C.

Tornatzky, L.G., Waugaman, P.G. and Gray, D.O. (eds) (2002) *Innovation U: New University Roles in a Knowledge Economy* Southern Growth Policies Board

Trune, D. and Goslin, L. (1998) 'University Technology Transfer Programs: A Profit/ Loss Analysis' *Technological Forecasting and Social Change* 24 pp. 197-204

UKBI (2000) *The UK Incubation Impact Assessment Study Phase One: Key Literature Review* UK Business Incubation, Birmingham

UNICO-NUBS (2002) *Annual UNICO-NUBS Survey on University Commercialisation Activities: Financial Year 2001* Nottingham University Business School, Nottingham

US Council on Competitiveness (1998) *Going Global: The New Shape of American Innovation.* Washington September

van der Laag, A. and Snijder, J. (eds) *Entrepreneurship in the Netherlands: Knowledge Transfer, developing high-tech ventures.* Ministry of Economic Affairs and EIM Business and Policy Research, the Hague, the Netherlands

Waasdorp, P (2002) 'Innovative Entrepreneurship: A Dutch Policy Perspective' in Entrepreneurship in the Netherlands: Innovative Entrepreneurship. New Policy Challenges EIM Business and Policy Research and Ministry of Economic Affairs February, pp. 27-42

Waugaman, P.G. and Tornatzky, L.G. (eds) (2001) *Benchmarking University- Industry Technology Transfer in the South and the EPSCoR States: 1997-1998* Southern Growth Policies Board

Wessner, C.W. (ed.) (1999) *The Advanced Technology Programme: Challenges and Opportunities,* Washington D.C. National Academy Press

Zucker, L.G. Darby, M.R. and Brewer, M.B. (1998) 'Intellectual Human Capital and the Birth of US Biotechnology Enterprises' *American Economic Review,* 88, pp 290-306

Zucker, L.G. and Darby, M.R. (1996) 'Star Scientists and Institutional Transformation: Patterns of Invention and Innovation in the formation of the Biotechnology Industry' *Proceedings of the National Academy of Sciences*, 93(3), pp. 12709-16

Zucker, L.G. and Darby, M.R. (1998) 'Capturing Technological Opportunity via Japan's Star Scientists: Evidence from Japanese Firm's Biotech Patents and Products' *NBER Working Paper No 6360* NBER