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DEVELOPING SKILLS FOR INNOVATIVE INDUSTRIES: THEORY; EVIDENCE FROM THE UK LIFE SCIENCES INDUSTRY; AND POLICY IMPLICATIONS

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Abstract: This paper explores how innovative firms attempt to acquire the skilled technicians needed to deploy new technologies. Interviews with 40 employers from the UK life sciences sector reveal that shortages of technicians, an awareness of the importance of practical skills best acquired through work-based learning, and increasing dissatisfaction the use of graduates, are encouraging employers to turn towards apprenticeship training. However, the rules governing the funding of various kinds of education and training discourage providers from offering the kinds of apprenticeships increasingly sought by employers, giving rise to a 'system failure' that manifests itself in shortages of technicians and the use of over-qualified graduates in technician roles.

Keywords: Technicians, innovation, skills, training, apprenticeships, system failure.

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1. INTRODUCTION

This paper explores two, closely related questions. First, how do innovative firms seek to acquire the skilled technicians they need to deploy new technologies? Second, to what extent are their efforts supported or impeded by the institutions governing the provision of various kinds of education and training? These are important questions, not least because under the auspices of the current industrial strategy government policy in the UK emphasises both the importance of developing innovative, high-value manufacturing and the need to train more skilled technicians of the kind that will be required as and when those sectors expand (HM Treasury and the Department of Business, Innovation and Skills 2011; HM Government 2017). Nor are these questions relevant only to the UK. Governments in several other countries are also grappling with them as they attempt to develop their domestic industries in the face of rapid technological change and increasingly fierce global competition (see, for example, Dalitz and Toner 2016 for the case of Australia, Bonvillian and Singer 2017 on the USA, Sung and Raddon on Singapore and Liu and Finegold 2017 for China).

Innovation is the process whereby new technologies are created and diffuse through the economy to create new products and novel methods of producing existing goods and services. It involves the invention of completely new ideas and the use of existing ideas by organisations that have not hitherto employed them. It is the means through which new knowledge is applied to economic processes in order to increase productivity, national income and living standards (OECD 2005: 46-52, 2015: 3-4; BIS 2011: 1-2, 7-22). Defined thus, innovation clearly depends critically on the work of highly-qualified research scientists and engineers, who drive the research and development through which new ideas are developed (BIS 2011: 111-14; Jones and Grimshaw 2016: 109). Good managerial skills are also important for ensuring the effective use of new knowledge and novel technologies (Bloom *et al*. 2014; HM Government 2017: 169). But there is another kind of worker who plays an important but in comparison to graduates neglected role in innovation, namely technicians (Tether *et al*. 2005; Toner 2011; Makkonen and Lin 2012). Technicians are workers occupying roles that require ‘intermediate’—that is, level 3-5—skills in science, technology, engineering and/or mathematics. The category encompasses both ‘skilled trades’, such as laboratory technicians and maintenance engineers, and ‘associate professional/technical’ roles (examples of which include some varieties of manufacturing technician and production engineer) (Mason 2012). Most significantly for what follows, technicians are intimately involved in the installation, commissioning, operation and maintenance of new technologies, thereby contributing to the ‘absorptive capacity’ of the firms that employ them (that is, to the ability of those firms to make effective use of innovative technologies) (Cohen and Levinthal 1990: 128-33; Jones and Grimshaw 2016: 112-15; Mason *et al*., 2019). Where the skills of the technician workforce are deficient—because of shortages of technicians, or because their skills are too specific, or because they lack theoretical knowledge—firms will suffer from poor absorptive capacity, lacking the capability to deploy new technologies to good effect. This in turns lead to slower innovation, lower productivity growth and reduced competitiveness (Prais 1995; Mason and Wagner 2005).

The question therefore arises of how innovative firms fill the technician roles required to deploy new technologies. That is the question addressed in this paper, which investigates how employers in two innovative parts of the UK life sciences sector attempt to acquire the technicians they need and how their efforts are facilitated or impeded by the working of the education system. Data were collected via interviews with 40 employers in industrial biotechnology (IB) and cell therapy (CT), with the research questions posed and the analysis of the data being informed by two complementary analytical perspectives: the theory of human capital (HC); and innovation systems (IS) theory. HC theory emphasises how employers' decisions about the balance to strike between recruitment and various kinds of training are shaped by incentives reflecting such factors as the ease with which appropriately-skilled workers can be recruited and the mix of theoretical knowledge and practical skills needed to deploy the technology in question. The research reported below investigates employers' views about whether, and if so how, the factors identified as potentially significant by HC theory influence their decisions about how to fill technician roles.

But the research reported below goes beyond HC theory, drawing on the IS literature to address a shortcoming in the theory of HC. Where the latter has been used to explore the relationship between skills and technological change, as in the seminal contribution of Nelson and Phelps (1966), it is typically assumed that education and training providers automatically adjust their offerings to what is required for firms to obtain appropriately-skilled workers. Such models therefore ignore the possibility that providers may sometimes fail to offer the relevant kind of training, hindering firms' ability to deploy new technologies. This paper explores whether in seeking to train technicians employers experienced such problems. In doing so, the paper draws on recent work in the IS literature, most notably Vona and Consoli (2014), to consider explicitly the role of education providers in enabling, or hampering, the development of the requisite skills, thereby helping to address the lacuna in HC theory. Moreover, by exploring the role of technician skills and training in innovation, the paper also helps to fill a widely acknowledged gap in the IS literature, which in its efforts to explore the relations between skills and innovation has focused almost exclusively on universities and graduates, largely ignoring technicians and providers of vocational education and training (VET) (Borras and Edquist 2015: 225; Jones and Grimshaw 2016: 112, 124). The paper thus contributes both to the literature on HC and also to the field of IS.

Key findings are that, in keeping with HC theory, shortages of technicians, an awareness of the importance for the deployment of new technology of practical skills of the kind best acquired via work-based learning, and increasing dissatisfaction with the shortcomings of over-qualified but under-skilled graduates, are all encouraging employers in IB and CT to turn towards apprenticeship training as a means of acquiring technicians. However, the evidence also indicates that employers have struggled to persuade training providers to offer the requisite education and training. These problems are symptomatic of what the IS literature refers to as a ‘system failure’, arising in this case because the rules governing the funding of various kinds of education and training discourage providers from offering the technician training increasingly sought by employers.

The structure of the paper is as follows. Section 2 describes two important theoretical perspectives, provided by HC theory and the IS approach. The third section describes the methods used for the empirical part of the research, the results of which are described and analysed in Section 4. The fifth section considers the policy implications of the research, including an innovative policy response inspired by the findings reported below. The sixth section summarises and draws conclusions, bringing out the significance of the findings reported here for the relationship between skills policy and industrial policy and making suggestions for future research.

2. THEORETICAL PRESPECTIVES

Two theoretical perspectives will be used to identify possible influences on firms’ efforts to fill technician roles, namely: HC theory; and the IS literature.

2.1 Human capital theory

The theory of HC under imperfect competition portrays employers as choosing between various ways of filling technician roles, deciding first of all what balance to strike between recruitment—hiring workers who already possess the relevant skills—and training (Katz and Ziderman 1990; Stevens 1994). Employers face a labour market where—because workers’ skills are valuable only to some firms, for example, or because employers are uncertain about workers’ skills—they can pay skilled workers a wage below their marginal product without losing them to other firms. Employers therefore have an incentive to invest in training because the wage premium paid to newly-trained workers is less than the increase in their marginal product. Moreover, recruitment is costly, because the higher wages needed to attract skilled workers must also be paid to current employees. Employers will minimise the costs of acquiring the technicians they need by relying on a combination of training and recruitment, with the role of training increasing as its marginal cost declines relative to that of recruitment (Stevens 1994: 537-41; Wolter and Ryan 2011: 524-38).

Employers may also fill technician roles by recruiting graduates. This may be an appealing option where there is an abundance of graduates, the ready supply of whom means that they are willing to apply for technician roles (Mason 2012: 27; Wolf 2015: 73-74). The consequence of such behaviour is a situation characterized by over-qualification; the highest level of formal qualifications possessed by the workers in question exceeds that required to carry out their job effectively (Wolf 2011: 29; Green 2013: 52, 170). The use of graduates will be less attractive, however, if the technology being used requires workers to possess practical skills of the kind people are unlikely to acquire at university and if the nature of technician work leads over-qualified graduates to become dissatisfied with their lot.

Employers choosing to train technicians can utilise apprenticeship and/or up-grade training. Apprenticeships combine a structured programme of on-the-job training and productive work with part-time, formal technical education; are oriented to the requirements of the relevant occupational labour market; normally take at least two years to complete; are usually formally certificated; and equip people with intermediate (level 3-5) skills (Ryan *et al*. 2007: 129; Brockmann *et al*. 2010: 61-62, 102-15). The broad range of skills, and the sound grasp of underlying theory, acquired by apprentices means that they are well placed to respond to the challenge of deploying new technology, enhancing the absorptive capacity of the firms that employ them (Prais 1995; Tether *et al*., 2005: 6-7, 55-56; Toner 2011: 33-36, 45-48). Upgrade training, in contrast, is typically closely tailored to the immediate requirements of particular jobs in specific organisations; may be offered either to recent recruits or to more established employees, with a variety of prior levels of educational attainment; is usually provided on-the-job, with little off-the-job technical education; and is also often uncertificated. Upgrade training is therefore more limited in content and duration, and so cheaper, than apprenticeship. Nonetheless, employers will have reason to prefer apprenticeship where skill requirements and the need for underpinning knowledge are high (Ryan *et al*. 2007: 137-38, 149 n. 18). In particular, the narrow range of skills imparted by upgrade training, and the paucity of technical education, limits the capacity of workers trained under this regime to support the successful deployment of new technologies, potentially hampering innovation (Prais 1995, Tether *et al*., 2005: 56, 60-61; Toner 2011: 47). In practice, of course, employers may well rely on a combination of recruitment, apprenticeship, and upgrade training. Explaining what combinations are used by specific kinds of employers is a key empirical question explored by this paper.

2.2 Innovation systems theory

A second perspective is provided by the literature on IS. An IS is the set of organisations and institutions governing the diffusion of new technologies through the economy (Lundvall 1992: 2; Edquist 1997). The key idea is that firms' efforts to devise and deploy new technology involve them interacting with many other organisations, including other firms, universities, banks, regulatory agencies, and providers of VET. Those other organisations act as sources of the knowledge, finance, skills, and other kinds of resource required for innovation. The institutions are the rules governing how those organisations interact with each other, and include the rules of corporate governance, contract and intellectual property law, and the terms on which government support is provided to organisations engaged in various kinds of education and training. By structuring how the relevant organisations that contribute to innovation interact with each other, these institutions are an important influence on the quantity and kind of innovation that takes place (Lundvall 2007, Edler and Fagerberg 2017).

One of the main reasons for the development of the IS approach was dissatisfaction with the old, science-centric model of innovation that had dominated innovation studies and policy in the first thirty years after the end of World War Two. According to the latter, new knowledge is created through fundamental research undertaken by highly-qualified scientists and engineers and then applied straightforwardly to create novel products and production processes. From that perspective, the main challenge facing policy-makers is to catalyse the production of scientific knowledge, the diffusion and application of which will—it is assumed—happen more or less automatically (Smith 2000: 85-86, 92-93; Weber and Truffer 2017: 103). The continued influence of this perspective can be seen in the emphasis of much current industrial policy on scientific research, with targets for investment in research and development and an emphasis on high-level skills pitched at bachelors level or above (Toner 2011: 8; Keep and Mayhew 2014: 7, 10; Jones and Grimshaw 2016: 109; Kitson 2019: 299-300, 302). However, the linear view has been criticised for ignoring the importance of other significant influences on the development and diffusion of new technologies, including suggestions made by final users (von Hippel 1988) and—most significantly for the purposes of this paper—the contributions made by technicians. First, technicians contribute to incremental innovation (that is, the gradual improvement of existing products and technologies, as distinct from the introduction of completely new ones). The ideas behind such incremental gains are typically born out of intimate familiarity with technology of the kind technicians acquire through their experience of operating, maintaining, and solving problems with the relevant machines and processes. In performing their duties, therefore, technicians learn how technology can be improved, enabling them to contribute to the creation of the knowledge for incremental innovation (Filippetti and Guy 2016: 506-07, 515; Lewis 2019: 10-12, 18-21). Second, as noted above, the technicians who commission, operate and maintain new technology play a critical role in its diffusion, contributing significantly to the absorptive capacity of firms (Mason *et al.*, 2019).

An important recent contribution to the IS literature that is helpful in analysing the issue of whether firms are able to acquire the skilled technicians they need to develop and deploy new technologies focuses on the role of educational organisations in facilitating, or hampering, the development of the requisite skills (Vona and Consoli 2014).[i] Although concerned mainly with universities, this approach can also be used to analyse the role of providers of VET in innovation. The key idea is that of 'knowledge systematisation', defined as the "standardisation of novel best practices and … their diffusion by means of changes in the content of education and training" (Vona and Consoli 2014: 1394). This idea is used as a conceptual device for connecting technology, institutions and skills. Initially, when a new technology is first developed, the activities associated with it tend to be complex, ill-defined, and the preserve of a small number of highly-qualified researchers. The relevant knowledge is mostly tacit, and therefore difficult to transfer without personal interaction. As the technology matures, however, it becomes possible to articulate and systematise the relevant knowledge in standard operating procedures that can be carried out by technicians (as required for the efficient scaling-up of production to full-scale manufacturing). As this occurs, organisations involved in education and training need to offer the relevant programmes, so as to facilitate the training of workers with the requisite skills and knowledge (Vona and Consoli 2014: 1394-99, 1404; also see Tether *et al.*, 2005: 7-8, 96-97; Toner 2011: 29).

If they do not do so—if the relevant education and training organisations are absent, or if the institutional rules governing their behaviour are inappropriate—then there arises the possibility of coordination failures, whereby the education system fails to align the accumulation of human and physical capital, focusing on one kind of skills (graduate, say) and neglecting others that are needed to exploit novel technology (for example, technician-level skills). Such coordination failures lead to structural mismatches between the stocks of physical and human capital that manifest themselves in problems such as shortages of technicians, deficiencies in technician skills, and/or the use of over-qualified but under-skilled graduates in technician roles (Vona and Consoli 2014: 1400-05; Andreoni 2014: 60-62, 65).[ii] Such problems limit the absorptive capacity of firms, restricting their ability fully to exploit new technology (DBIS 2014: 22-23; Borras and Edquist 2015: 222-25). Failings of this kind are 'system failures' in the sense in which that term is used in the IS literature; the institutional framework within which innovation occurs is inadequate to coordinate all the activities required to ensure that new technologies are developed and diffuse properly through the economy, in this case because the organisations governing VET do not supply firms with the particular kinds of human capital required to make best use of new technology (Metcalfe 2005; BIS 2011: 52-53, 111-17).[iii]

3. METHODS

Data were drawn from employers seeking to innovate by deploying new technologies in two parts of the UK life sciences industry: cell therapy/regenerative medicine; and industrial biotechnology (hereafter, CT and IB respectively). CT is a field of medicine involving the replacement or regeneration of human cells, tissues or organs in order to restore normal function (Mason and Dunnill 2008). It is a completely novel technology, whose development has only recently reached the point at which research and process development work is being translated into production on a commercially-viable scale (Cell and Gene Therapy Catapult 2016: 8-10). IB involves the application of knowledge of living organisms to industrial products and processes in order to provide goods and services. It is an enabling technology that can be used across a variety of sectors, including pharmaceuticals, energy, and agriculture. Its use is well-established in some sectors and firms—for example, in some parts of food- and medicines-manufacturing—but it is also being applied to transform production in other sectors (as exemplified by the development of bio-fuels) (UKCES 2015a: 10-11). At the around the time this research was undertaken, the total IB workforce was estimated to be around 38,000 people. Estimates of the total CT workforce are unavailable; it forms a (small) part of the medical biotechnology sector, which employs just under 23,000 people. Both are amongst the fastest growing science sectors, whether growth is reckoned in turnover or employment. Estimates indicate that the two sectors will generate at least 5000 additional technician-level jobs by 2025 (SIP 2016 6-7, 13-14). In keeping with this, both sectors are amongst the 'Eight great technologies' that UK policy-makers have identified as having the potential to become major markets and, if successfully developed, to bring significant benefits to productivity, growth and exports (Willetts, 2013; DBIS 2014: 85-88, 140-43; HM Government 2017: 33, 194).

In the absence of large data sets covering the use of technicians by employers in these sectors, and the ways in which organisations seek to fill technician roles, a qualitative approach was adopted. Data were collected through semi-structured interviews with employers, using an instrument that was piloted in early interviews. Employers were identified in a variety of ways: through secondary sources (such as industry reports and official government publications); suggestions made by informed third parties (including representatives of government departments, sector skills councils, and trade bodies); and attendance at three industry-level conferences. Additional cases were added until 'closure', in the sense of the continued observation of phenomena that had already been observed, was reached (Eisenhardt 1989: 545). The representativeness of the sample of checked by reference to industry documents and informed third parties. The goal was to identify a set of organisations that would make it possible to explore a variety of different determinants of employers' use, and sourcing, of technicians, including: whether the organisations were mainly involved in research and development, process development or full-scale commercial manufacturing; the particular type of technology being used; and the local labour market conditions in which the employers were situated (Eisenhardt 1989: 537).

Accordingly, in addition to being asked basic factual questions about the number of technician roles in their organisation, and how those roles were filled both in the past and the present, interviewees were invited to reflect on how, if at all, the factors identified by the theories outlined above—such as ease with which different kinds of worker can be recruited, the balance of theoretical knowledge and practical skills required to operate the relevant technology, and the willingness of training providers to offer appropriate programmes—influenced their decisions about whether to create technician roles and how to fill them. Interview data were also supplemented by notes taken from participation in industry conferences and workshops, as well as secondary sources (such as government and industry body reports).

Interviews were carried out in 2015 and 2016 with 29 employers in IB and 11 from CT. Information was collected via 37 interviews with a total of 44 interviewees in IB and 16 interviews with 12 interviewees in CT. Interviewees included HR and training managers, operations directors, and chief technology officers. Notes were written up immediately after the interviews and, where gaps were revealed, these were filled via email follow-up. Primary and secondary documentation, such as job descriptions and training syllabi, was also collected where possible. The cases, which were drawn from all four nations of the United Kingdom, are summarised in Table 1 (with details of the individual organisations provided in Tables 2 and 3 in the Appendix)

4. RESULTS AND ANALYSIS

4.1 The size of the technician workforce

The organisations visited for this study varied according to whether they currently specialise in R&D (working at the laboratory level to develop new products and processes), process development (exploring how novel products and processes can be produced at greater scale), or manufacturing (at full, commercial scale). The distribution of cases—with a total of 16 being in R&D, 11 in process development and 13 in manufacturing—reflects the way that both IB and CT employ emerging technologies, many aspects and applications of which are still under development. Moreover, the situation is dynamic in the sense that many organisations are in the midst of expanding their operations, with a total of 15 firms in IB and 7 in CT expanding in scale (including 6 that are also increasing in scope, with 3 organisations moving from R&D to process development and 3 from the latter to full-scale, commercial manufacturing) (see Table 1).

[INSERT TABLE 1 ABOUT HERE]

In both IB and CT, the share of technician roles rises as organisations shift from R&D to process development to full-scale manufacturing. As organisations expand the scope of their activities, there is an increase in the volume of routine manufacturing and laboratory support work of the kind that can be carried out by people qualified to intermediate level rather than by graduates. "The method is already set up for them [via standard operating procedures]", an interviewee explained. "It's like following a recipe [so] you don't need a degree." This facilitates a more elaborate division of labour, leading to an increase in the absolute number of laboratory and (in particular) manufacturing technician roles and a rise in their share of the workforce. As the chief operating officer of one expanding CT firm put it, "As the manufacturing side grows, and as manufacturing becomes a more routine process … we will have specialist cell culture technicians trained in GMP manufacturing." Given that many firms in both CT and IB are expanding in this way, the trend towards an increasing number and share of technician roles seems set to continue.

4.2 Sources of the current technician workforce

Firms have in the past adopted a variety of approaches to filling technician roles. These differences reflect the factors identified as potentially important by HC theory.

By far the most common approach used to fill laboratory technician roles is recruitment, but not of genuine technicians (understood as people possessing intermediate-level qualifications). Rather, 22 employers reported that they obtained most of their laboratory technicians by hiring graduates. Firms advertising such positions typically receive few applications from genuine technicians, but are usually inundated with applicants qualified to degree level and above in the chemical and biological sciences, who can be hired at relatively low wages (cf. Lewis and Gospel 2015: 431). As one interviewee commented, 'We'd like to hire a technician, but all we get applying are graduates." The consequence is "a real mismatch" between level of qualifications people need to fill those roles effectively and level they possess. These findings are consistent with the theory outlined in Section 2, which suggest that where there is an abundant supply of graduates who (employers believe) possess the relevant skills and knowledge, and where genuine technicians are scarce, then firms will recruit graduates to fill technician roles. As the manager of one IB firm explained, "If there's a load of graduates looking for jobs, so supply is high, why not take them? They're cheap, the supply's there [and] you don't have to give them day release … [so] firms can get lazy and just recruit graduates."[iv] Whether this strategy works as successfully as employers hope depends on whether their expectations about the suitability of graduates for technician work are borne out, an important issue discussed below.

A majority of firms in IB and CT reported that in developing their current manufacturing technician workforce they had struggled to recruit people who could slot straight into such roles without additional training. “Trying to get hands on process technicians is hard,” one IB manufacturer observed, “they’re rare … [so] recruitment is time-consuming and costly.” Firms responded to these difficulties a variety of ways. One common approach, adopted by all 4 of the CT firms that currently have manufacturing technician roles and by 3 IB firms is to recruit over-qualified graduates. Significantly, all three of the IB firms are ones where production centres on laboratory-style cell cultivation, the skills for which employers believed science graduates would possess. In acting on this belief, employers sought to minimise the costs of filling technician roles by tapping into the abundant supply of bioscience graduates. The same approach could not, however, be adopted by 6 other IB firms whose production facilities closely resemble large-scale chemical plants. Those firms recognised that their manufacturing technicians needed skills in process operations that can be acquired only through a lengthy period of work-based training (rather than at university). They therefore acquired most of their manufacturing technicians via an approach best described as a hybrid of recruitment and work-based upgrade training. This involved them hiring experienced chemical process operators, who were readily available on their local labour market and were skilled in running large-scale industrial plants, and then giving them additional on-the-job training in the specific methods used in IB manufacturing. This was a cheaper way of filling technician roles than using apprenticeships because the workers had received much of the relevant training elsewhere.

A more conventional kind of upgrade training was utilised by 4 other IB firms, who filled manufacturing technician roles by hiring people with little prior experience of process operations, such as school leavers, and training them from scratch in the specific practical skills needed to be a manufacturing technician in their organisation. The use of this strategy reflected the fact that, in contrast to the organisations described in the previous paragraph, these 4 firms are not situated in areas where experienced chemical process operators, ripe for upgrading, are readily available for hire. However, the approaches adopted by both sets of firms resembled each other in that training was typically provided on-the-job by more experienced staff members, was typically uncertificated, and did not involve off-the-job technical education at a local college.

A smaller number of firms—one contract manufacturer and one process developer—had made some use of apprenticeships to fill manufacturing technician posts. Like the organisations that relied on upgrading, these two firms valued work-based training as a means of equipping trainees with practical skills in cell cultivation. But they also required their employees to possess significant amounts of underpinning knowledge, and so required trainees to take significant amounts of off-the-job technical education—HNCs in Applied Biology in one case, Foundation Degrees in Applied Bioscience Technology in the other—so that the training in question constituted an apprenticeship. The reason is that the two firms need their manufacturing technicians to be very adaptable, adjusting to different methods of production depending on the particular product being made or process being developed; and they believed that such flexibility requires them to have both the broad range of skills and also the underpinning knowledge of cell biology and microbiology provided by apprenticeship training (but not by upgrading). This is, of course, consistent with HC theory, according to which employers will prefer apprenticeships to upgrading where a broad range of practical skills as well as a solid grasp of underlying theory are required.

A similar rationale underpinned the use of apprenticeship training by 5 out of the 10 IB firms who discussed how they acquired their maintenance technicians. While those firms reported that they found it easy to hire experienced electrical and mechanical maintenance technicians, and so typically relied on recruitment to satisfy their need for such workers, it was widely held that the control and instrumentation technicians were in short supply. Given the need for such workers to possess excellent practical skills as well as a sound grasp of physics and mathematics, the combination of on-the-job training and off-the-job technical education provided by an apprenticeship training was deemed the best way of responding to the scarcity of such workers on the external labour market.

4.3 Sources of the future technician workforce

We move on now to consider how employers in CT and IB plan to fill technician roles in the future. The strategies they are using mark a significant departure from those upon which they relied in the past. At the time of this study, 7 IB employers had recently started to train apprentice laboratory technicians, having not previously done so, while 9 organisations (4 in IB and 5 in CT) had either recently started training apprentice manufacturing technicians or were seriously planning to do so.

The underlying cause of this increased reliance on training is the continued expansion of the two industries, which is—as noted above—leading to the creation of more technician roles (in particular, manufacturing technicians). Employers in both industries therefore expect the recruitment difficulties they experienced in the past to continue, encouraging them to turn towards apprenticeships: 'We can't get the technicians off the shelf," one IB manufacturer remarked, "so we take apprentices." The turn towards apprenticeship training also reflects the way many firms (8 in IB and 8 in CT) have realised that the strategy of hiring graduates to fill technician roles is flawed. It brings short-term benefits in the form of cheap labour; but it also gives rise to problems. First, while graduates possess more theoretical knowledge than is required of a technician, they also often lack the requisite practical skills. As a senior manager from one IB firm lamented, "students are very well educated in the theory but their practical skills are appalling." This problem reflects what one study describes as a "possibility that often gets overlooked – that graduates are less capable in some occupations than the non-gradates they are displacing" (Holmes and Mayhew 2015: 12; also see UKCES 2015b: 46). Second, graduates occupying technician roles often become dissatisfied both with the mundane, highly-routinised nature of their duties and also with the relatively low wages they receive. The consequence, as one operations manager put it, is that "they quit because they're looking for [more] exciting, challenging, stretching work." This leads to higher labour turnover than if the roles were filled by genuine technicians, to the chagrin of employers (especially those who invested time and money in remedying the graduates' deficient practical skills).

The employers who have adopted apprenticeship training emphasise several benefits. One is the superior practical skills possessed by ex-apprentices. As the manager of an IB process development firm put it, "If you compare apprentices and people who've been to university for the same length of time, the apprentices are more highly skilled than the graduates … They're experts in the techniques." But if apprenticeship's emphasis on practical skills accounts for its increasingly being preferred to the recruitment of graduates, its superiority over upgrade training arises from the way that it still involves significant off-the-job technical education (typically up to level 4-5, in the case of manufacturing technicians in IB). Employers valued the underpinning knowledge of cell biology, chemistry and microbiology provided by that part of the apprenticeship for at least two reasons: first, because it helped to inform technicians' decisions about how to act, within the confines of the standard operating procedures (which inevitably afford workers a measure of discretion about how to go about their duties); and, second, because a knowledge of the underlying theory helps employees to understand why adhering to the standard operating procedures and regulatory requirements is important, thereby encouraging compliance.

The increasing popularity of apprenticeship training sheds light on the question—upon which the literature acknowledges more research is needed—of the balance employers aim to strike between the practical skills and tacit knowledge best acquired through work-based learning and the explicit, theoretical knowledge acquired at university (Mason 2012: 25-27; Jones and Grimshaw 2016: 112). The evidence reveals that employers are increasingly recognising the importance of practical skills of the kind best acquired through a work-based route. As one employer put it, "Cell culture and clean room behaviours[v] are 'hands on' activities, which people learn by doing … having people trained in the field makes a big difference to how well they can do the job." The implication is clear: the best way to teach the skills in question is through the practical, work-based learning that is so central to good apprenticeships. And, of course, the latter also affords workers the opportunity to acquire the theoretical knowledge employers also need them to have if they are to do their job well.

Significantly, however, 6 IB employers who sought to take apprentice laboratory and/or manufacturing technicians faced difficulties in persuading local further education colleges and training providers to offer the requisite education and training. First, employers have struggled to find colleges willing to offer the requisite off-the-job technical education (typically level 3 qualification in Laboratory and Related Technical Activities, in the case of laboratory technicians, or HNCs in Applied Biology, in the case of manufacturing technicians). Second, they also found it hard to persuade providers to offer high-quality practical training in basic cell cultivation and the use of clean rooms under cGMP regulations.[vi] As one training manager put it, "There is no college capable of giving us what we currently want." The proximate cause of these difficulties lies in what might be called 'the tyranny of small numbers', namely the problem that while more and more employers are seeking to take apprentices, often the total number of trainees is too low to make it worthwhile for providers to offer the relevant courses, given (i) the high fixed costs of developing them—of building clean rooms in which trainees can learn how to cGMP manufacturing protocols, for example, and of acquiring tutors expert in the latest techniques—and (ii) the prevailing funding regime. (None of the case study employers takes more than 6 apprentices per year.) This leads as a situation where, as one frustrated training manager put it, “We get lost in a sea of other interests.” Similar difficulties have been experienced by employers in other emerging parts of advanced manufacturing in England (Lewis 2012: 31, 2013a: 5, 46-47; Lewis 2013b: 31-32). It is perhaps significant that these problems were experienced by firms located in England, but not by their Scottish counterparts (which are able to train apprentices via an HNC in Applied Biology).[vii] It is in recognition of this that the following discussion focusing on England rather than the other parts of the UK (cf. Keep 2014).

This issue will be analysed further, using the IS framework outlined in Section 2 above, in the next section of the paper, where we will also consider—using CT as an example—how such difficulties can be avoided even given the dysfunctional nature of the prevailing funding regime.

5. POLICY IMPLICATIONS

5.1 System failure in the provision of vocational education and training

The findings presented above—of shortages of skilled technicians, the extensive use of over-qualified but under-skilled graduates, and the reluctance of providers to offer the relevant programmes—are symptomatic of a deeper malaise within the English VET system. There is widespread evidence that skilled technicians are in short supply (UKCES 2015: 66-71; HM Government 2017: 37-38, 48, Augar 2019: 25, 49-50). The use of over-qualified graduates is significant both in absolute terms, with between a quarter and a third of employees falling into that category (UKCES 2015: 7, 57), and also comparatively, with estimates suggesting that the scale of the problem is greater than in most other European nations (Green 2013: 131-32, 179-83; OECD 2013: 171; Holmes and Mayhew 2015: 25-28). Other manifestations of the ‘missing middle’, as the failure to train a sufficient number of technicians has been described, include the fact that the workforce has a lower share of workers with intermediate-level skills and a smaller number of apprentices in training than its international competitors (Steedman 2010, Augar 2019: 20, 26, 33-34).

These findings reflect what the IS literature refers to as a ‘system failure’, stemming in this case from the rules governing the provision of education and training, which afford employers, providers and trainees insufficiently sharp incentives to develop the mix of technician and graduate skills required to facilitate the deployment of new technologies to best effect. Two aspects of the problem may be distinguished. First, the rules governing the provision of financial support make loans available to those studying for degrees but not to apprentices, while the rules governing investment in different kinds of teaching afford more generous support for universities than further education colleges. This has led to a systematic bias in favour of university education:

> [C]urrent arrangements set up an interconnected set of incentives which result in young people opting for full time degrees (level 6) and in institutions marketing and supplying full degrees at maximum price to the near-exclusion of other options. (Augar 2019: 37; also see House of Lords 2018.)

Second, even to the extent that colleges and other training providers offer apprenticeships, funding rules encourage them to offer shorter, cheaper, more basic (level 1-2) programmes, in subjects such as customer service and business administration, rather than the longer, more expensive, advanced (level 3-5) apprenticeships in science and engineering required by employers in advanced manufacturing. This reasons are twofold: first, the shorter, lower-level courses are easier to pass, so that it is easier for providers to claim funding for them under the current ‘output-related’ funding system; and, second, for any given level of difficulty, if a provider offers a large number of shorter courses, then the risk of it suffering an unexpected shortfall of income because of an unusually high number of failures in any one group is reduced if that risk is spread over a larger number of cohorts. In this way, funding arrangements “drive providers away from higher technical provision” (Augar 2019: 37; also see Wolf 2015: 5-6, 9-12 and Augar 2019: 122-30, 149-50). Problems are especially acute in “emerging or small sectors” such as IB and CT:

> Developing new courses is always risky, especially if they require large amounts of equipment or the hiring of very specialist staff; given current conditions, launching

> new high-cost provision at level 4 or 5 is additionally risky and financially unattractive. (Augar 2019: 26, 37.)

The outcome is a situation where providers often lack the incentive to offer the kinds of courses needed by employers in advanced manufacturing who wish to train apprentices. Hence the difficulties faced by employers in the aerospace, composites and space industries, as well as by those considered in this paper, when they attempt to find training providers willing to offer the courses their apprentices need (Lewis 2012: 31; 2013a: 5, 46-47; Lewis 2013b: 31-32).

In short, the rules governing the provision of education and training in England are such that there is a systemic failure to align workforce development and technology development, leading to a structural mismatch between the economy's requirements and the kind of skills being produced that manifests itself, as described above, in employers experiencing shortages of skilled technicians, in the use of over-qualified but under-skilled graduates in technician roles, and in a reluctance on the part of education and training providers to support employers' efforts to train apprentices. Ultimately, dealing with such problems requires significant reform of those rules, as set out in the recent Augar Review (2019; also see House of Lords 2018: 42-53). Rather than rehearsing those arguments here, however, we turn instead to a concrete example of how matters can be improved even within the current over-arching set of rules (not least because, at the time of writing, it is unclear which if any of the Augar Review's recommendations will be implemented by policy-makers).

5.2. <u>How to build technician skills for an emerging technology: An example</u>

The initiative in question stems from the finding, reported above, that CT employers are looking to employ increasing numbers of technicians. This finding was acknowledged by the Advanced Therapies Manufacturing Taskforce, an industry-led group created in 2016 order to "identify actions that the UK must consider taking in order to anchor manufacturing of advanced therapies in the UK and capture investments to secure the UK position as a world class hub" (Medicine Manufacturing Industry Partnership 2016: 3). Having accepted that the development of a technician workforce was necessary for that goal, the Taskforce secured funding first of all from the Gatsby Charitable Foundation, which supported the research reported in this paper, and subsequently from Innovate UK, to finance the creation of a CT manufacturing technician apprenticeship scheme. 18 apprentices began training in September 2018, with 40-50 signed up to start in September 2019.

The apprenticeship has a number of features which help to ensure its viability, even in the face of the 'tyranny of small numbers'. First, it involved the creation of one centre of excellence, located in an area with a high concentration of growing CT employers, namely London. This helped to ensure that there was a reasonable demand for places on the scheme from local employers. Second, the off-the-job technical education, which involves apprentices studying for level 3 and 5 qualifications in subjects such as Applied Bioscience Technology, was provided by distance learning, so that the programme is accessible to firms situated further afield, increasing interest and helping to ensure that the number of apprentices reached the 'critical mass' required to ensure viability. Third, the initial financial outlay associated with the provision of some of the practical training, such as cell cultivation under clean room conditions, was reduced through the use of existing facilities (rather than the construction of entirely new ones). The facilities in question are housed in the Cell and Gene Therapy Catapult Centre and are accessed by apprentices during periods of block release from their employer (cf. Lewis 2014: 509; Bonvillian and Singer 2017: 225).[viii]

The Catapult Centre is also the institutional 'home' of the apprenticeship training scheme. This brings another advantage, because—thanks to its role in assisting the development of emerging technologies—the Catapult is familiar with new manufacturing processes and is therefore well placed to harvest information about the skills and knowledge technicians will need. In order to exploit this opportunity, the funding provided by Gatsby and Innovate UK was used to support the creation of an 'expert educator team' within the Catapult (Bonvillian and Singer 2017: 235-36). This consisted of a small group of people who were knowledgeable about both science and education, and who worked with employers and the catapult to collect information about the skills and knowledge needed to exploit new technologies, to translate it into statements of competence and job descriptions, and to collaborate with education and training providers to develop appropriate training programmes. In this way, the expert educator team engaged in the 'knowledge systematisation' required to develop the content of a formal apprenticeship training programme to support the diffusion of new technologies (Vona and Consoli 2014: 1397-99). The team also served a second important purpose, connected with the fact the CT employers were typically SMEs who lacked a well-developed HR function familiar with apprenticeships. Thanks to the team's knowledge of the apprenticeship system, it was able to assist SMEs in recruiting apprentices, dealing with training providers, and navigating the requirements of the apprenticeship system. The team thus relieved employers of much of the administrative burden of taking apprentices, thereby removing a significant barrier to their involvement (cf. Lewis 2014: 505; Bonvillian and Singer 2017: 230-31; Augar 2019: 155).[ix]

6. CONCLUSIONS

This paper has examined how employers in two branches of advanced manufacturing acquire the skilled technician labour they need to support the commercialisation of new technologies. It finds evidence to support both HC and IS theory. Incentives reflecting the kinds of factors emphasised by HC theory are important in shaping employers' decisions about how to fill technician roles. In particular, shortages of technicians and the abundance of graduates has in the past encouraged employers to fill technician roles by recruiting people with bachelors degrees. More recently, however, increasing employer dissatisfaction with the use of over-qualified but under-skilled graduates has led to a turn towards apprentice training. This reflects is an increasing recognition on the part of employers in IB and CT of the importance for the successful deployment of new technologies of practical skills of the kind best acquired through a work-based route.

The paper has also described how IB employers seeking to train apprentices have often struggled to persuade providers to offer the relevant off-the-job technical education and/or training in relevant practical skills such as the use of clean rooms and cGMP manufacturing. Such problems reflect an underlying 'system failure' of the kind identified in IS literature, stemming in this case from the way that the rules governing the funding of various kinds of education and training have discouraged providers from offering the technician training increasingly sought by employers. In highlighting this problem, the paper contributes to the literature on IS, which has focused almost exclusively on the role of universities and graduates rather than technicians and VET, as well as filling a gap in HC theory (which typically assumes that providers automatically adjust their offering to suit employers' demands).

The paper also has important policy implications. First, in identifying a case of system failure, the paper suggests that the English VET system is unlikely to supply in sufficient numbers the skilled technicians required to facilitate the development of innovative, high-value manufacturing. Radical reform of the rules governing the provision of VET, along the lines suggested in the recent Review of Post-18 Education and Funding, is required (Augar 2019). Second, if such reforms prove politically infeasible, the paper also shows how, as in the case of the CT apprenticeship, it may nevertheless be possible to establish a suitable apprenticeship scheme, thereby providing potentially useful lessons for initiatives in other emerging parts of advanced manufacturing.

The need for institutional reforms of the kind just described to facilitate the timely development of a technician workforce to support the deployment of new technologies reflects a broader point, namely that skills policy ought to be treated as an integral part of—rather than, as is so often the case, an afterthought to—industrial policy (Green and Mason 2015: Section 10.4; Keep 2017: 681-83, 686). The latter all too often focuses on technology development and R&D, with policy on skills in general, and intermediate-level skills in particular, being relegated to a footnote. This arguably reflects the continued influence of the outdated, science-centric model of innovation described in Section 2.2 above. The consequences of this approach have been described in a recent speech by Andy Haldane, the chief economist of the Bank of England:

> Typically, we think of 'Research and Development' (R&D) as a rhyming couplet. In the UK's case, the R and the D do not seem to rhyme. The UK does R well, as a world-leading innovation hub. But it does D poorly, where the D refers not just to development but the diffusion and dissemination of innovation … When it comes to innovation, the UK is a hub without spokes. (Haldane 2018: 7).

Haldane's point is that the science-centric, research-focused approach provides a misleading account of innovation, because it neglects other significant influences on the development and diffusion of new technologies, including those arising from the work of technicians. As emphasised above, the skilled technicians who commission, operate and maintain new technology play a critical role in its diffusion; if there is a deficit of technician skills, then firms will lack the absorptive capacity required to exploit fully the potential of new technology to create value and increase productivity. It is for this reason that two American commentators have argued that "education and training programmes should not be a sideline but rather a key part of the technology development and dissemination effort" (Bonvillian and Singer 2017: 225).

Moreover, as also noted above, technicians can also contribute to the incremental improvement of existing technologies. However, the extent to which workers actively engage in such bottom-up, incremental innovation is strongly influenced by the how their jobs are designed and work is organised (Toner 2011: 3; Jones and Grimshaw 2016: 110). There may therefore also be a role for public policy in providing firms with advice and guidance about how to design jobs and organise work so as to promote incremental innovation (Froy 2013: 351-58; Keep and Mayhew 2014: 7, 24-29; Lewis 2014: 509-10). Such an approach affords another example, along with the role of the Catapult Centres in 'knowledge systematisation', of how skills policy could form part of a more holistic approach to industrial policy that would do justice to the complex interdependencies between innovation, skills, job design and work organisation (Wilson and Hogarth: 2003: 75-80; Vorley and Nelles 2019: 4-7, 11, 15).

Further research is needed on several of the issues discussed in the present study. First, in the case of England, to what extent will the new Institutes of Technology, which are supposed to support high-level technician training, deal with the problem of 'tyranny of small numbers' and thereby improve firms' ability to access technician-level training for emerging technologies in a timely manner? Second, what has been the impact of the Scottish government's acceptance of the Reid Review of Innovation's insightful remark that "[t]he delivery of skills is not some sort of 'secondary' innovation - developing new skills and techniques to apply alongside new technological innovation is vital if such developments are to be embedded and made truly a commercial success" (Reid 2016: 38; Scottish Funding Council 2017)? Third, to take a wider international focus, how do other countries address the issue of 'knowledge systematisation'? Do they rely on institutions like catapult centres, as described in the CT case discussed in Section 5.2 above, or on other kinds of institutional arrangement? Fourth, the research described above has focused on sectors that are relatively new in the sense that many firms have only just begun full-scale manufacturing. It would be important also to explore whether, and if so how, more established parts of manufacturing, such as automotive and food processing, are addressing the need to (re)train their technicians to deal with the disruptive impact of new digital technologies. Fifth, and finally, if the scope of policy is extended to include measures designed to promote incremental innovation, then more research will be needed on the balance between intermediate and higher-level skills, and the particular kinds of workplace organisation, best suited to exploiting technicians' potential to contribute to that goal in different sectors. This research can help to inform the design of policies that will embody a genuine commitment to a more integrated and coherent approach to skills and industrial policy.

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Appendix Table 2: Attributes of case study organisations in industrial biotechnology, arranged by principal activity

Activity	Name	Total employment	Number of technician roles	Expanding?	Involved in Apprenticeship training
Research and development	IBR1	50	1	Yes	Yes
Research and development	IBR2	35	4	No	No
Research and development	IBR3	6	1	Yes	No
Research and development	IBR4	9	1	Yes	No
Research and development	IBR5	9	0	Yes	No
Research and development	IBR6	6	0	Yes	No
Research and development	IBR7	70	0	No	No
Research and development	IBR8	300	0	No	No
Research and development	IBR9	560	11	No	Yes
Research and development	IBR10	20	0	No	No

Research and development	IBR11	50	12	No	Yes
Research and development	IBR12	8	1	Yes	No
Average for research and development	-	*94*	*3 (3%)*	*(6 out of 12)*	*(3 out of 12)*
Process development	IBPD1	12	0	Yes	No
Process development	IBPD2	43	5	No	No
Process development	IBPD3	40	0	Yes	No
Process development	IBPD4	256	23	Yes	Yes
Process development	IBPD5	40	8	Yes	Yes
Process development	IBPD6	40	6	Yes	Yes
Process development	IBPD7	2	0	Yes	No
Average for process development		*56*	*6 (11%)*	*(6 out of 7)*	*(3 out of 7)*

Manufacturing	IBM1	200	120	Yes	Yes
Manufacturing	IBM2	48	20	No	No
Manufacturing	IBM3	59	8	Yes	Yes
Manufacturing	IBM4	25	1	No	No
Manufacturing	IBM5	90	??	No	Yes
Manufacturing	IBM6	700	450	No	No
Manufacturing	IBM7	550	120	No	Yes
Manufacturing	IBM8	320	50	Yes	Yes
Manufacturing	IBM9	120	??	No	Yes
Manufacturing	IBM10	90	45	No	Yes
Average for manufacturing		*220*	*102 (46%)*[1]	*(3 out of 10)*	*(7 out of 10)*

Appendix Table 3: Attributes of case study organisations in cell therapy, arranged by principal activity

Activity	Name	Total employment	Number of technician roles	Expanding?	Involved in Apprenticeship training
Research and development	CTR1	10	0	Yes	Intend to
Research and development	CTR2	45	0	Yes	No

[1] Excludes two organisations for which data on number of technician roles could not be obtained.

Research and development	CTR3	8	1	No	No
Research and development	CTR4	12	2	No	No
Average for research and development	-	*19*	*1 (5%)*	*(2 out of 4)*	*(1 out of 4)*
Process development	CTPD1	45	4	Yes	No
Process development	CTPD2	75	3	Yes	No
Process development	CTPD3	30	2	No	No
Process development	CTPD4	22	1	No	Intend to
Average for process development		*43*	*3 (7%)*	*(2 out of 4)*	*(1 out of 3)*
Manufacturing	CTM1	40	10	Yes	No
Manufacturing	CTM2	50	5	Yes	Intend to
Manufacturing	CTM3	20	2	Yes	Intend to
Average for manufacturing		*37*	*6 (16%)*	*(3 out of 3)*	*(2 out of 3)*

Table 1: Summary of Case Studies (by industry and specialism)

Industry	Specialism	Number of cases	Average number of employees	Average share of technician roles in the workforce
Industrial biotechnology	R&D	12	94	3%
	Process Development	7	56	11%
	Manufacturing	10	220	46%[2]
Cell therapy	R&D	4	19	5%
	Process Development	4	43	7%
	Manufacturing	3	37	16%

ENDNOTES

[i] The research begins from a shortcoming in HC theory, which typically assumes that providers automatically offer the kind of courses required to enable firms to acquire the skilled labour they need to exploit new technologies. Thus the possibility is ignored that providers may fail to adjust their offerings appropriately, hindering the adoption of the technology in question (Andreoni 2014: 58, 60; Vona and Consoli 2014: 1394-95, 1400).

[ii] This is in addition to the possibility, long discussed in the literature on human capital, that there may be a market failure to invest adequately in skills due to employers' fear of poaching (Stevens 1999; Mohrenweiser *et al*., 2019).

[iii] Such system failures constitute an impediment to innovation that is distinct from the conventional neoclassical category of 'market failure', as they relate to the way that the institutions that help constitute markets works rather than to markets *per se* (Metcalfe 2005: 54-60; DBIS 2014: 11-20). Another problem highlighted by system-theoretic approaches but not by HC theory centres on the possibility of so-called low-skills equilibria, whereby firms become locked into a self-reinforcing combination of workforce and product-market strategies that sees them employ a poorly qualified workforce to manufacture low-cost, low-value added goods that compete in world markets on the basis of price rather than quality (Finegold and Soskice 1988). While there is considerable evidence that significant parts of British industry have indeed suffered this fate (Green and Mason 2015: section 10.3), the two parts of the life sciences sector considered here deploy technologically-sophisticated methods of production to manufacture high-value added products using, as we shall see below, a highly-skilled workforce. They therefore appear to be far removed from being in a low-skills equilibrium.

[iv] As Alison Wolf has explained, "Higher education subsidies mean that employers are often able to displace a sizeable part of the training they used to do on to higher education institutions. Even if the training is less specific to their needs, and even without the work the apprentice does, they are often at least as well off as under apprenticeship, if not better off … [so] employers will inevitably recruit as far as possible from graduates" (2009: 96).

[2] This estimate of the share of technicians in the IB workforce is likely to underestimate the true figure, as two of the best-established manufacturers, in which the share of technicians is likely to be greatest, are unable to supply relevant data.

[v] The manufacturing of cell therapies, and also of many products made by firms in IB, regenerative medicine takes places in carefully controlled spaces designed to prevent contamination, known as clean rooms, and in keeping with the regulatory requirements of clinical Good Manufacturing Practice (cGMP).

[vi] The very high cost of decontaminating clean room facilities in the event of a breach of protocol means that employers consider them unsuitable for basic training on the part of new apprentices who are, naturally, prone to making errors. Hence the firms' desire for apprentices to learn the basics of cell cultivation under clean room conditions at a college. After completing that initial training programme in general cull cultivation and clean room behaviour, the apprentices would then be ready to receive further, more specialist practical training in the specific techniques used by their employer at their place of work. The practical skills in basic cell cultivation under clean room conditions that employers wish their apprentices to learn in college are highly transferable, being useful—employers stated—to a variety of different firms not only in the advanced therapies industry but also in the life sciences sector more generally (e.g., in biologics and pharmaceuticals). If labour markets are imperfectly competitive, then some of the benefits to which those skills give rise will accrue to firms that did not contribute to their creation, a positive externality whose existence provides a rationale for the provision of some government financial support for the training in question (Stevens 1999: 19-23; Hogarth and Gambin 2017: 660-61). However, the support in question should be only partial because, as noted in Section 2.1 above, firms that equip their workers with transferable skills do stand to earn a positive return on their investment in training (albeit less than the full social return). As well as paying (state-subsidised) fees to the relevant colleges, firms seeking to display genuine 'employer leadership' in training may also contribute by helping to train college tutors in current best practice and by donating capital equipment to help ensure that college facilities are up-to-date (Lewis 2013a: 58, 2013b: 39, 2019: 27 n. 16).

[vii] In Scotland the geographical concentration of employers in these industries has helped to ensure the existence of a critical mass of apprentices within reach of an FE college with a long tradition of apprenticeship training in STEM subjects. The college in question has worked both with those employers and also with the IBIOIC, an organisation involved in technology development in industrial biotechnology, to devise an HNC syllabus appropriate for apprentices training to work with those emerging technologies.

[viii] Catapult Centres are technology centres where universities, businesses and government work together to encourage the commercialisation of new technologies. Their goal is to reduce the risks associated with the development of such technologies, by providing facilities and expertise to demonstrate that the technologies in question can work not just at the laboratory level but at full, commercial scale.

[ix] Another way of viewing the Catapult Centre's efforts in helping firms with the management of their apprentices is as an example of the kind of advice and assistance that firms might need when some of their managerial skills, in this case concerning the management of training, are deficient (Green 2013: 142, 150; Borras and Edquist 2015: 221)