Shortage or surplus? A long-term perspective on the supply of scientists and engineers in the US and the UK

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Abstract

A 'crisis account' of shortages of well-qualified scientists, engineers, mathematicians and technologists has shaped education policy in the UK and the USA for decades. The apparent poor quality of school science education along with insufficient numbers of well qualified teachers have been linked to skills shortages by government and other agencies since at least the time of the Second World War. There is, however, an alternative account that challenges the received view of a skills deficit and questions the evidence for sustained and long term shortages across the sector. This paper provides a historical account of some of the main events that have characterised debates over the supply and demand of science and engineering professionals in the UK and the USA and the implications that this has had for science education policy. Starting from the end of the Second World War, the paper looks at the key challenges to the evidence that underpins the shortage debate and considers the consequences that more than seven decades of crisis accounts have had on the recruitment and retention of highly skilled scientists and engineers. The paper shows that while the shortage debate has a long history, it is one that is characterized by poor quality data as well as methodological and conceptual challenges. It argues that there is no consensus view about the existence of a skills deficit and that while there may have been short-lived shortfalls in specialist areas, there is little evidence in support of widespread and far reaching shortages as the rhetoric often claims.

Introduction

> "To communicate the spirit of science and to develop people's capacity to use its values should be among the principal goals of education in our own and every other country" (Educational Policies Commission, 1966:27).

The role of science within a nation's education system has long been the focus of much discussion and debate. Whether the purpose of school science education is to provide scientific training in preparation for university and a scientific career, or whether it is to educate a scientifically literate population has been contested ever since the subject was first taught in schools (e.g. Taunton Committee 1868, The Royal Society 2008, Donnelly and Jenkins 2001). This dual function of school science epitomises a tension between scientific literacy as a pre-requisite for active citizenship in a modern society and a view of scientific knowledge as a tool for economic growth, prosperity and security. In forming education policy it has usually been the latter purpose that has prevailed.

Thus the economic imperative that conflates science education policy with science policy has manifested itself in well-established concerns over the quality of science teaching, the content of the science curriculum and the perceived inadequacy of science graduates. These are issues that have dominated discourse in this area for decades. Driving these concerns, and their implications for science education policy, has been the longstanding belief that there is a shortage of highly skilled workers in the key areas of Science, Technology, Engineering and Mathematics[1] (STEM).

A nation's prosperity is no longer linked to its physical and natural resources but is instead driven by its human capital. In the field of science, technology and engineering the strength of this human capital is directly linked to the size and quality of the workforce (Teitelbaum, 2014). Numerous corporate and government bodies have considered the supply of this workforce and have found it wanting. As a consequence, policymakers have responded to calls from industry, government and universities to enact policies and initiatives – often involving the investment of large public funds – that are aimed at remedying the situation.

These concerns about the supply of highly skilled STEM workers have been central to public policy on education, science and engineering in the USA and the UK since at least the time of the Second World War (e.g. Bush 1945, Steelman 1948, Cmd. 6824, 1946). The literature in this field is vast but has kept to the same basic reasoning for the past 70years: that there is a shortage of highly skilled science and engineering graduates, arising in part because of poor quality science teaching in schools, and that these shortages are detrimental to a nation's technological and economic development. However, behind the apparent consensus is a much more complex reality. As this paper will show, 'moral panics' about the future supply of a highly skilled science and engineering workforce have influenced the direction of education policy for decades. Yet shortage claims are inconsistent with the substantial body of evidence that has accumulated over the last seven decades, largely as the result of research by economists and other labour market analysts.

This paper takes the end of the Second World War as its starting point and considers the pivotal stages in the development of a crisis account of the supply and demand of science and engineering professionals in the UK and the USA and its parallel influence on science education policy. This long-term perspective provides an important context for the shortage debates that underpin contemporary policy discourse surrounding the education, recruitment and retention of highly qualified scientific personnel. The need for this type of historical account in policy research is important as in the rush to develop and implement new policies and initiatives there is often little or no regard for the longer or even medium term effects of past reforms (Tyack and Cuban, 1997).

The literature in this field is considerable and cannot be effectively summarized in a single paper. What is possible, however, is to provide a chronological overview of some of the key stages in the evolution of the shortage debate and to look at some of the shortcomings and challenges to the evidence that underpins it. It is also possible to consider the consequences that more than seven decades of crisis accounts have had for education policy as well as for the recruitment and retention of highly skilled scientists and engineers. The literature reviewed here has been drawn from a range of sources, including government committee reports and transcripts, policy documents, other grey literature as well as from peer-reviewed academic publications. As the purpose of the paper is to provide a historical account of the STEM shortage crisis, most of this literature was published between the end of the Second World War and the mid-1990s, with links to more recent accounts and studies provided where appropriate.

The specific questions addressed in this paper are as follows:

1. **How has the policy debate over science and engineering shortages evolved in the UK and the USA from the end of the Second World War to the end of the Cold War?**

2. **What is the relationship between shortage concerns and science education policy over the period considered?**

3. **To what extent has there been a consensus view about the existence of a skills shortage?**

4. **What are the key methodological and conceptual challenges to understanding the supply and demand of scientists and engineers?**

5. **To what extent has the policy attention to this topic been matched by strong evidence of a shortage of skilled scientists and engineers?**

The paper begins by considering contemporary concerns about science education and its relationship with the supply of highly skilled scientists and engineers, before offering an historical overview of the evolution of the STEM shortage debate.

A ‘crisis’ in the education and employment of highly skilled scientists and engineers

> ‘...improving math and science education in our nation’s elementary and secondary schools is a prerequisite to achieving the economic gains to be had from technological innovation and to improving the distribution of those gains’ U.S. Congress Joint Economic Committee (2012:10)

Improving the recruitment, retention and training of the next generation of STEM professionals is a priority for policy makers and employer organisations in the UK and elsewhere (e.g. Cm 8980 2014, EU Skills Panorama 2012, National Academy of Sciences, 2010). According to the Confederation of British Industry’s most recent Skills and Education Survey, employers report widespread difficulties in recruiting people with STEM skills at every level: from new apprentices to more experienced workers. In addition over half of businesses (52%) report experiencing, or expecting to experience, difficulties in recruiting appropriately skilled STEM staff (CBI 2015). Surveys, also in the UK, undertaken by sector skills organisations paint a similar picture (e.g. IET 2015, Engineering UK 2015, ABPI 2015). In a society with increasing demands for scientific- and technological-based goods and services, a decline in the number of students studying ‘rigorous’ STEM courses at university is seen as one of our ‘greatest economic and intellectual threats’ (National Math and Science Initiative, 2015:n.p.).

These concerns, frequently reiterated by employer organisations, are reflected in the range and scope of initiatives, policies and reports that have been aimed at increasing young people’s participation in STEM subjects, particularly at post-compulsory levels. For example, in the UK a single month in 2016 saw the publication of two major reports into the employability of STEM graduates: *The Wakeham Review of STEM Degree Provision and Graduate Employability* (Wakeham Review, 2016) and *The Shadbolt Review of Computer Sciences Degree Accreditation and Graduate Employability* (Shadbolt Review, 2016). Both closely follow the extensive Perkins Review of Engineering Skills (BIS 2013) in emphasising the economic imperative of a strong and globally competitive STEM sector while at the same time reiterating similar shortcomings in the supply and skills of the STEM workforce. The recommendations coming from these reports, and numerous others, tend to focus on engaging more young people, in particular those from under-represented groups, in STEM subjects. However science has been a compulsory part of the national curriculum in England and Wales since 1989 and all students have been expected to spend a significant proportion (for many around 20%) of their time studying science from ages 14 to 16. **Yet the proportion of students studying STEM subjects (e.g. biology, chemistry, physics, mathematics and engineering) at university have remained remarkably stable over the last three decades, despite a four fold increase in the number of university entrants (Smith and Gorard 2011).** This suggests that compulsory school science has had little impact on the throughput of students studying the subject at university level and, subsequently, on the number of graduates who would be available to undertake highly skilled work in the sector. Nevertheless, policy makers are now promoting single subject science teaching and the number studying for separate (rather than the previous combined) qualifications in chemistry, physics and biology in England has doubled between 2007 and 2013 (Department of Education, 2015). This further broadening of the science curriculum has the explicit aim of increasing the number of young people studying science beyond the age of 16 (when the subject ceases to be compulsory) and, in turn, increasing the supply of scientists, engineers and technologists in the workforce (Fairbrother and Dillon, 2009).

In the US, the challenge for school science is slightly different - here the concern is that there is too little curriculum focus on the subject. Science is one of four core subjects that are repeatedly tested in school but, unlike mathematics and reading, science is not reported as part of a school's accountability data. According to some commentators, curriculum emphasis has switched to the subjects that do count in school accountability models and has resulted in a reduction in the time spent teaching science in school and in poor quality instruction (Marx and Harris 2006, Blank 2012). However, concerns over the focus on 'basic' education to the apparent exclusion of science (often not considered to be basic) have been a recurring theme in the development of science education policy in the country. The impetus behind programs to promote science education, however, is not primarily a concern for the intrinsic value of learning science or the creation of a scientifically literate workforce. Initiatives to encourage participation in science and to increase the amount of science taught in school are frequently driven by the discourse of a skills shortage of STEM workers and the purpose of this paper is to consider the strength of these shortage claims over the long term.

One of the main destabilizing effects of the shortage thesis on science education has been the frequent conflation of the apparent shortage problem to all levels of education. The remedy for which is to teach more science in school which, in time, is expected to translate to more highly skilled STEM workers (e.g. NAS 2010, U.S. Congress Joint Economic Committee, 2012). But relatively few students (and usually only the most able) continue to advanced study and subsequent careers in science and engineering. In the US, for example, only about 5% of the workforce is in science and engineering related occupations (Teitelbaum 2014). In England this version of 'science for all' has meant that in order to address perceived workforce shortages in the IT industry (House of Commons

2013), computer coding and programming will now be taught from age 5 because: 'these are precisely the sort of skills which the jobs of the future - and, for that matter, the jobs of the present – demand' (Gove 2014, n.p). This, of course, is not to argue against the value of a scientific education. Exciting initiatives that promote more science for more students could be seen as an unequivocally positive development. Science in all of its forms is a fascinating and wonderful subject to study in and of itself, regardless of the need to rank highly in school accountability tables or to provide the next generation of highly skilled STEM workers. However there is undoubtedly a tension when shortage claims, and their subsequent impact on the wider school curriculum, are founded upon insufficient evidence and poor data.

The following section takes a historical perspective on the shortage debate in the UK and the USA. The main emphasis of the discussion is on two key time periods: the aftermath of the Second World War until the space race of the 1960s, and then the period towards end of the Cold War in the 1980s and early 1990s. Both periods effectively illustrate the role that fears of a shortage of suitably qualified workers have played in influencing science policy and education policy as well as providing an important overview of the evidence that has been presented to challenge and refute these shortage claims.

A crisis in supply? A chronology of the shortage debate

According to Teitelbaum the science shortage debate can be characterized as three stage cycles of alarm, boom and bust which have 'buffeted and destabilized' (2014: 2) the scientific and engineering workforce since the time of the Second World War. Throughout the more than seven decades in which these cycles have existed, concern has been guided by influential groups of lobbyists as well as corporate and political leaders, whose views have, more often than not, been shaped by flawed data, weak evidence and vested interests. In this section we consider some of the key documents that have shaped the shortage debate, we look at the impact these have had on education policy and the arguments that have been put forward to challenge the claims. We begin with the period from the end of the Second World War to the culmination of the space race in the 1960s.

From the World War II to the space race

> "The fast approaching bottleneck of too few scientists and technologists can well be the most efficient weapon possessed by Stalin and the Politburo" (Lessing, cited in National Science Foundation 1951:17)

From a US perspective, two reports published towards the end of the Second World War set the blueprint for 'persistent alarms' about the supply of scientific personnel

(Teitelbaum, 2014:2). Together these reports have provided the framework, and some of the data, for a shortage debate that has continued to the present (see Godin 2002). The first of the two reports was published in 1945 and followed President Roosevelt's commissioning of Vannevar Bush to investigate how the scientific and technological advances made during the War could be used in the 'days of peace ahead for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living' (Bush 1945:3). During the War Bush had played a celebrated role in mobilizing science and engineering talent in order to meet the demands of warfare (England 1982). His subsequent report '*Science: The Endless Frontier'* called for the use of public funds to strengthen scientific research and was instrumental in the establishment, in 1950, of the National Science Foundation (NSF) (Bush 1945, see also England 1982). The Bush report also projected a shortfall in the number of highly qualified scientists and engineers:

> 'The deficit of science and technology students who, but for the war, would have received bachelor's degrees is about 150,000. … The real ceiling on our productivity of new scientific knowledge and its application in the war against disease, and the development of new products and new industries, is the number of trained scientists available' (6).

Equally as explicit in its concerns about 'manpower' shortages, the *Science and Public Policy* report was published two years after the Bush report. Authored by J.R. Steelman, it estimated that in the years following the Second World War there would be too few scientists to ensure the post-War expansion of scientific research and development that the country needed. Projecting the availability of the workforce in the decade after the War, and basing these assumptions on the number of students already in the education pipeline, the report warned of a 'danger of a shortage of high-quality scientists' that would 'limit the substantial expansion of research and development programs that the Nation requires' (Steelman 1948: 57).

Shortage concerns were no less evidence in the UK, as Payne's review of official documents dealing with the issue made clear, 'the scientific and engineering manpower problem is one of the principle preoccupations of the British Government' (1960:11, see also Godin 2002, Lowell and Salzman, 2007). For example, the 1946 Barlow Report reviewed the policies that would be needed to govern the use and development of scientific 'manpower' and resources in the post-War decade (Cmd. 6824, 1946). It concluded that regardless of any efforts to increase the output of science graduates, 'the nation will be seriously short of scientists in 1950 and that without heroic efforts it is unlikely that supply will have finally overtaken demand even five years later' (para. 58).

As the following statements show, the sentiment and rhetoric that came from these post-War documents remains equally relevant today:

> Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress. (Bush, 1945:6)

> Science is more essential for our prosperity, our security, our health, our environment, and our quality of life than it has ever been. (President Barack Obama, Speech to the National Academy of Sciences, 2009)

The two decades following the end of the Second World War were characterized by a great volume of literature from government, industry and academic sources, on the supply and demand of highly skilled scientists and engineers (Godin 2002). The context for these concerns was provided by the launch of Sputnik by the Russians in 1957, the ensuing 'space race' and the start of the Cold War. It was reflected in rising government investment in science and technology both in the UK and the USA. For example, in the USA expenditure on research and development across all federal departments increased more than ten-fold in the space of a decade, from $73.4 million in 1940 to $839.6 million in 1950 (NSF 1951). Despite rising research costs over the period, this represents a large increase in government investment in the area, and one primarily funded by the taxpayer.

In the wake of the launch of Sputnik, the US House of Representatives convened a number of committees to investigate on-going scientific 'manpower' demands. Among them inquiries by the 86th and 87th Congress sought to determine the nature and the extent of the shortage (House of Representatives 1959 and 1963). Once again, of central concern was that recent expenditures in research and development (estimated to be around $50billion by 1960) had not been accompanied by corresponding increases in the supply of relevant 'manpower'. This led to projected deficits in the supply of scientists and engineers of around 17,000 for each year of the coming decade (House of Representatives 1963).

However, two key reports into science shortages published in the years preceding these inquiries by the House of Representatives provided a different perspective on the shortage debate. The first, authored by the economists David Blank and George Stigler, was published in 1957. It argued that since the Second World War demand for scientists and engineers in the United States had grown rapidly but not as rapidly as supply, with the consequence that salaries had drifted downward (similar trends were also apparent in the UK see Wilkinson and Mace, 1973). The report concluded that '…the number of engineers has been growing more rapidly relative to the demand in the past two and a half decades, than has been the case in the labour market as a whole' (Blank and Stigler 1957:31). A second report, by researchers at the Rand Cooperation, reached similar conclusions. The authors of this report pointed to several conceptual and analytical issues in 'dubious' previous work on projections (a point that will be returned to below) and express surprise at 'how little direct evidence of a shortage is available' (Alchian et al. 1958: iv). This scepticism over the reliability of techniques used to project future workforce demand is central to much criticism of the shortage discourse at this time. As Godin's overview of supply and demand for this period concludes: 'all in all the success of American predictions on the supply and demand of scientists and engineers was about zero: by 1968 all predictions of shortfalls had proved incorrect' (2002:11).

The aftermath of Sputnik

The political shock caused by the successful launch of Sputnik in 1957 brought into sharp relief what were, for some, the failings of the American education system and accompanying alarms that the country was falling behind in scientific and engineering leadership (Teitelbaum, 2014). It is difficult to underestimate the lasting impact that the launch of Sputnik had on American public life, its sense of security and on its education policy in particular (see for example NCEE 1983, Dow 1991, Ravitch 1995, Obama 2011). But the following from the then President of MIT and chair of the President's Science Advisory Committee (PSAC), provides some sense of the immediate impact that it caused:

> 'In an age when science is essential to our safety and our economic welfare, it might be argued that a shortage of science teachers and of scientists and engineers is a clear and present danger to the nation' (Killian, 1957:78).

In short, the post-War era was a period of sustained criticism of the American public school system and these concerns were heightened by the launch of Sputnik (Caswell 1954, Dow 1991). The main challenges for public education at the time can be summarised as follows (and will be familiar to today's reader). Too many talented young people were dropping out of science education, curriculum programmes were inflexible, teaching was of poor quality and the supply of science teachers was 'decimated' (Killian 1956:118). Such shortcomings, it was claimed, were amplified by anti-intellectual attitudes and values in America society that were complicating efforts to increase the supply of scientists and engineers and criticised 'a surprising amount of fear of science and of a misreading of what science really is' (Killian 1956:125).

As Dow has argued, Sputnik prompted an era of school reform and expenditure of federal funds that was of 'unprecedented scale' (1991:251). In 1958, in one of the earliest government responses to the event, President Eisenhower signed into law the most comprehensive education reform bill the nation had ever seen. Public Law 85-864, otherwise known as the National Defense Education Act, sought to ‘strengthen the national defence and to encourage and assist in the expansion and improvement of educational programmes to meet critical national needs’ (National Defense Education Act, 1958:1580). The Act committed $billions of federal funds for a range of education based reform activities - from higher education loans and new initiatives for vocational education; to funds to establish and maintain national testing programmes as well as for research and experimentation in the more effective use of new media (television, radio, motion pictures) for educational purposes. The Act sought to ‘correct as rapidly as possible the existing imbalances in our educational programs which have led to an insufficient proportion of our population educated in science, mathematics, and modern foreign languages, and trained in technology’ (National Defense Education Act, 1958: sec 101). Thus the immediate post-Sputnik era was characterised by unprecedented federal involvement in the US public education system. Public education, an area that constitutionally is the preserve of each individual state, was now the focus of huge federal curriculum development projects, of increased scrutiny and was subject to a new era of international comparative tests that have been used by governments ever since to inform policy decisions about weaknesses and strengths in their school systems (Suter 2016, NAR 1983).

Scientific and engineering research and development in the 1960s was driven by the continued tensions of the Cold War. In the USA, the technological advances precipitated by President Kennedy’s commitment to the ‘space race’, coupled with huge financial investment, gave rise to further concerns about the adequacy of present and future supplies of scientific and engineering manpower. Over the decade, federal investments rose and fell in cycle with the urgency of concerns about the Soviet Union’s scientific and technological advancement (see Teitelbaum 2014 for a fuller discussion).

At a similar time in the UK, a series of reports commissioned by the Committee on Scientific Manpower also focused on the recruitment and retention of scientists and engineers and on providing estimates of future needs (e.g. Cmnd. 902, 1959; Cmnd. 2146, 1962; Cmnd. 3102, 1966). Their conclusions can be summarized as follows: while the output of qualified scientists and technologists continues to grow, demand continues to rise and employers continue to report a shortfall; in short ‘we are still some way from a satisfactory balance of supply and demand’ especially in some disciplines (Cmnd. 2146, 1962:21). However, this received view of a shortage was again challenged by economists who argued that the available evidence ‘casts severe doubt on the accuracy of forecasts ... which throughout the 1960s consistently indicated an impending shortage of engineers’ (Wilkinson and Mace, 1973:111, see also: Gannicott and Blaug, 1969, Mace 1977).

In 1963 the British Government commissioned Lord Robbins to review the medium and long-term expansion of Higher Education and, in particular, to consider how the sector would cope with the predicted shortfall of university places caused by the large numbers of young people who were born after the War and who would be eligible to enter higher education after 1965 (Cmd. 2154, 1963). In advocating for the 'massive' (para. 383) expansion of the Higher Education sector, the Robbins Committee also recommended an increase in the types and numbers of institutions that would provide scientific and technical training. However, increased recruitment to Higher Education as advocated by Robbins arguably had a less desirable impact on entry to the sciences. According to the Dainton committee (commissioned in 1965 to examine the flow of candidates into science programs at university) unlike the arts and social science subjects where recruitment in schools and universities remained robust, the proportion of candidates admitted to study science and technology at university had fallen since the beginning of the decade. This in turn promoted fears that if things continued as they were, university science faculties would find themselves 'increasingly recruiting rather than selecting candidates' (Cmnd 3541, 1968, para. 6). The report goes on to describe 'the persistent dearth of suitably qualified candidates in science ... and, conversely, an embarrassingly high number of well qualified candidates for arts and social studies' (para. 31). The Dainton committee's list of recommendations aimed at redressing the purported 'swing from science' still echo in calls for reform of the British education system to this very day: the need for a broader range of subjects to be studied post-16 so that decisions whether or not to study STEM subjects at university were postponed as late as possible; for all pupils to study mathematics until they leave school; the need for good science teaching for all, and so on (Cmnd 3541, 1968, also Hillman 2014, Select Committee on Science and Technology, 2012). The main tenet of these reforms was that in order to increase the supply of future scientists all students should study more science in school to 'give the individual a broad educational background ... to reverse movement away from science at school and to increase the flow of potential qualified manpower' (Cmnd 3541, 1968, para.172). Such calls underpin wider attempts to increase recruitment that Sir Solly Zuckerman, chair of several Committees on Scientific Manpower in the late 1950s and 1960s (see above), would later refer to as 'propaganda' (Zuckerman 1968:20).

The launch of Sputnik and the start of the Cold War had a huge impact on education and science policy, especially in the USA. It succeeded in convincing the public and policymakers alike that the scientific and military challenges posed by the USSR could only be addressed by more effective scientific education and training (Dow 1991). However, once the USA had outpaced the Soviet Unions with the successful moon landing in 1969, public concern about education began to wane and along with it federal investment in school reform programmes. The focus of education policy returned to curriculum 'basics' (which did not always include science) and localised priorities – as education in the USA is, after all, a state and not a federal domain.

The end of the Cold War

The election of President Ronald Regan in 1981 coincided with a renewed focus on the state of US public education and an emphasis on reversing falling or stagnating test scores nationally as well as poor performance on international comparative tests. In 1983 – 'the year of the reports' - nearly 50 reports totalling more than 6000 pages voiced concern over the troubled state of American education, an outpouring of criticism overshadowing even that of the 1950s (Dow 1991:243). Three reports published around this time, each aptly capturing the sentiment of the time, are worth considering further.

Possibly the best known report – *A Nation at Risk* – recalled the fears of the 1950s by equating educational strength with national security. It presented a searing indictment of the poor educational standards that, it claimed, were 'eroding' the American public school system:

> Our Nation is at risk. Our once unchallenged pre-eminence in commerce, industry, science and technological innovation is being overtaken by competitors throughout the world…The educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future - as a Nation and a people… If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war (NCES 1983:5).

A Nation at Risk emphasised national economic competitiveness as the motivating factor behind educational reform, with scientific and technological illiteracy as key components in the failure of the country to keep up with the demand for highly skilled workers. The two other reports *Educating Americans for the 21st Century* and *Science and Engineering Education for the 1980s and Beyond*, were also explicit about the need to improve mathematics, science and technology education. In deriding the complacency that followed the moon landings and subsequent emphasis on 'basic skills' education these reports expressed concern over declining emphasis on mathematics and science education and the deteriorating quality of instruction in schools, fearing 'a lack of competitive edge' (NSF 1980:10) compared with Japan, Germany and the Soviet Union. They reiterated the need for scientific and technological literacy among the general population and emphasised the link between the quality of science and technology education and the country's economic strength and military security:

> '…the Nation can ill afford an attitude of complacency regarding the education and utilization of professional scientists and engineers' (NSF 1980:25)

To ensure that mathematics, science and technology education would, by 1995, be the 'finest in the world' (NSF 1983:7), the now familiar calls were made for better qualified teachers, more effective instruction, better use of IT, more curriculum time for mathematics, science, technology teaching and further federal mechanisms for measuring and monitoring student participation and attainment and for addressing the 'severe' (NSF 1983:10) shortages of qualified mathematics, science and technology teachers.

During this time shortage concerns largely focused on the economic significance of the science and engineering workforce and the need for improvement in educational performance at all levels (e.g. NCES 1983, U.S. Congress Joint Economic Committee 2012, Cm. 8980, 2014). These concerns tended to be issued by corporate employers, especially those in the IT industry; government agencies, including those that finance research and education in science and engineering such as the NSF; the education establishment, both compulsory and post-compulsory, for whom shortage claims provided a rationale for further investment; and finally from immigration lawyers and advocates who have used the shortage debate to support expansion in the numbers of permanent and/or temporary visas for overseas workers, especially in the US (Teitelbaum 2014).

The NSF workforce projections

In the USA, shortage debates in the early post-Cold War period were marked by controversial workforce projections published by analysts at the National Science Foundation. These reports signalled an important stage in the treatment of data on the science and engineering workforce and are worth considering in more detail. In the mid to late 1980s the NSF started to circulate a series of working papers that estimated a shortfall of 675,000 scientists and engineers by the first decade of the new millennium (Committee on Science, Space and Technology 1992, Weinstein 2002, Hicks 2009). This 'impending crisis' in supply was rooted in the 'incontrovertible demographic fact' (Holden 1989:1536) that low birth rates in the 1960s and 1970s had resulted in a shrinking of the college-age population and a subsequent decline in the pool of potential scientists and engineers. It was argued that this shortfall would be exacerbated by the fact that new additions to the workforce were mainly women and those from black and Hispanic backgrounds, all of whom were traditionally 'grossly' under-represented in science and engineering occupations and would be less likely to enter jobs in these fields (Holden 1989:1536, also Committee on Commerce, Science and Transportation 1990).

The NSF reports were never officially published, nor were they peer reviewed or subject to rigorous methodological critique. Nevertheless, they were widely circulated as evidence of an impending crisis in future supply (Committee on Commerce, Science and Transportation 1990, also Weinstein, 2002). They were also presented as evidence to Congressional Subcommittee inquiries about the nature, extent and consequences of an impending crisis, as this exchange between Eric Bloch, then Director of the NSF, and Senator Gore, Chair of the Subcommittee, illustrates:

> Senator Gore: … if you were a betting man, what kind of odds would you give that there will in fact be, without changes in current policy, a serious shortage of well-qualified scientists and engineers by the year 2000?
>
> Mr Bloch: Two to one…because of the demographics and solely because of the demographics, namely the decline in the 22-year-old population, and with no change in the attraction rate of the people and the students going into science and engineering, that a shortfall would exist of roughly 675,000 people by the year 2000 or 2005' (Committee on Commerce, Science and Transportation, 1990:25).

The data that informed the 675,000 figure was based on projections that about 5% of 22 year-olds would achieve BSc degrees and that 5% of these would attain PhDs, while also taking into account the number of white males (the key science and engineering demographic) in the workforce. These estimates were supported in evidence provided to the same Subcommittee by Richard Atkinson, chairman and retiring president of the American Association for the Advancement of Science (AAAS), who expressed even greater certainty that there would be a shortfall in supply:

> You asked Mr Bloch if he would make some estimates on the likelihood of these shortages. It is too complicated a question to ask, but I would be betting more like 100 to 1 that we are going to have dramatic shortages (statement by R. Atkinson, Committee on Commerce, Science and Transportation 1990:36).

However, less than one year after the Director of the NSF and the President of the AAAS had claimed with such certainty that a crisis was inevitable, the NSF reports had been retracted and publicly ridiculed (Committee on Science, Space and Technology, 1992). The main criticism of the reports was their basis on a simplistic view of how the labour market worked by focusing only on the supply of new graduates while ignoring supply and demand mechanisms in the wider market economy: 'the world is not run or determined by 22 year olds' (comment by H. Wolpe, Committee on Science, Space and Technology, 1992:2, see also Fechter 1991, Weinstein 2002, Teitelbaum 2014).

As a consequence of these reports, the credibility of the NSF in predicting future workforce demand was seriously damaged and the surrounding controversy prompted further Congressional hearings in 1992 that were convened in order to discover how 'a study so flawed survived for so long in the Nation's premier scientific agency' (Committee on Science, Space and Technology, 1992:2). But repeated use in speeches, testimonies, articles and news stories meant that despite recognized flaws in the NSF data, the 675,000 shortfall figure had taken on a 'life of its own':

> 'That prediction, delivered up in the context of growing concerns about our Nation's competitive standing, was the equivalent of shouting 'fire' in a crowded theatre. Many in Congress, the Executive, the media, and in the private sector focused on that number and used it in many, many fora to support their particular policy preferences' (statement by S. Boehlert, Committee on Science, Space and Technology, 1992:7, and for examples see Hicks 2009, Turney and Donnelly 1990, Atkinson 1990)

Crucially, as is discussed later, the NSF reports were also influential in determining future policy on the immigration of highly skilled scientists and engineers to the United States, as well as in securing large increases in federal funding for science and engineering education (Teitelbaun 2014, Weinstein, 2002)

As this brief chronology has shown, concerns about shortfalls in the supply of highly qualified scientists and engineers have persisted in the UK and the USA since at least the end of the Second World War. These shortage claims have been inextricably linked to the calls for more and better quality science and technology education at compulsory and post-compulsory levels and have resulted in large increases in funding for STEM education and training. While the evidence used to support these shortage claims has frequently been challenged, usually by labour market economists, the rhetoric contained in these arguments is strong, and the 'shortage' discourse has succeeded in becoming the dominant political and public view. However, as the National Science Foundation example has shown, there are important conceptual and methodological challenges to determining supply and demand in this context, and some of these issues are considered next.

Conceptual and data issues with describing a 'shortage'

As discussed above, the empirical basis for 'shortage' concerns is questionable and often 'rests on a limited range of assumptions about expected demand' (Hansen et al., 1967:206, see also Mace 1977). In trying to understand why some of these conceptual confusions have arisen, it is worth looking first at what is meant by three key terms:

'scientists', 'engineers' and 'shortages'. While this focus on the conceptual and data issues that underpin the shortage discourse is not directly related to education policy and practice *per se*, they are key to understanding the validity of the whole shortage narrative and therefore need to be considered here.

It is not unusual to encounter different definitions of who should be counted as a scientist or an engineer (and even the general terminology for these groups of subjects varies between STEM, SET and so on). In defining these roles it is usual to first consider educational background, so those with a bachelor degree or higher in the field of science, engineering or mathematics might be defined as a scientist or an engineer (although Wilkinson and Mace (1973) include those with sub-degree level qualifications). But the problem with this is that educational qualifications may bear little relationship to labour market definitions that tend to have an occupational focus (e.g. Wilkinson and Mace 1973, Mace and Taylor 1975). Although even here, different occupational categories are often used and Census definitions may differ from those used by professional bodies and so on (Blank and Stigler 1957). For example, the US National Science Foundation's current definition of scientists and engineers includes social scientists and categorizes a 'sociologist' as a science and engineering occupation (NSF 2014). Additionally, engineers, for example, may use their skills productively in jobs not categorized as engineering occupations but many in engineering occupations do not have engineering degrees (Fechter 1991). There are also those with science and engineering qualifications who work outside the field voluntarily, because the skills acquired when studying these subjects will be welcomed by employers who recruit, often for better paid, careers outside the sector (Teitelbaum 2014).

However it is in defining the term 'shortage' that probably the greatest complexity and ambiguity lies (Alchian et al., 1958, Meager 1986, Richardson 2007). When the term is defined, and often it is not, its use can differ depending on the conceptual and empirical techniques adopted by the commentator. To provide some clarification Blank and Stigler (1957) and Meager (1986) suggest three different circumstances in which a STEM 'shortage' *may* arise.

First a shortage might exist if the number of scientists and engineers is less than the number dictated by some social criterion or hypothetical demand. However, this definition is largely based upon a value judgment about what contribution science and technology *ought* to make to society and, in turn, often reproves society for having low demand for scientists and engineers (e.g. Alchian et al., 1958, Hansen 1961, Veneri 1999). As Arrow and Capron argue, the view that there are not as many engineers and scientists as the nation should have in order to secure a nation's economic, social and technological progress '…leads to the conclusion that it is really a shortage of *demand* for scientists and engineers that concerns them' (1959:307, emphasis added, see also Committee on Science, Space and Technology, 1992). This social demand model of shortages has arguably been the prevailing view in government and industry discourse over the period considered here. An example of this kind of thinking is illustrated in the following quotation:

> '…the fact that the number of young people selecting science and engineering careers has not increased during a generation in which science and technology pervades every aspect of our lives *is nothing less than an scandal'* (Atkinson 1990:430, emphasis added).

Secondly, a shortage may be seen to arise if the number of scientists and engineers that are needed is greater than the supply at the prevailing wage. If such a shortage exists, economists like Blank and Stigler (1957) (as well as those working in the field more recently) argue that wages would normally rise, causing the number of workers needed to shrink and the number supplied to expand. Thus the shortage would vanish as soon as the market has had time to adjust. This perspective is key to how economists and employers differ in their approach to measuring shortages and is returned to later. As Meager (1986:240) argues 'many so-called shortages are not true shortages if they arise simply because an employer cannot pay the going rate for a particular skill'.

Finally a shortage may exist when the supply of workers increases more slowly than the number demanded 'at the salaries paid in the recent past' (Blank and Stigler, 1957:22). If salaries then rise and activities which were once performed by engineers, for example, are now performed by less well trained and less expensive workers, that would then constitute a true shortage.

There is some consensus among labour market economists that in mixed economies the labour market would, in time, adjust to any shortage circumstances through changes to supply and demand (Teitelbaum 2014). However, the failure to reach a consensus on a single suitable definition of 'shortage' is largely due to fundamental differences in how the concept is understood by employers and labour market economists. Essentially this is based on a distinction between numerical shortages (not enough people to fulfil a particular role) and employers' desire for lower cost employees (meaning that there may be insufficient people willing to work for the wage that is being offered). This is apparent in the US Bureau for Labour Statistics definition of a shortage:

> 'Shortages occur in a market economy when the demand for workers for a particular occupation is greater than the supply of workers who are qualified, available and willing to do that job. Jobs remain vacant as employers seek to hire

more workers than are willing to work at the prevailing wage or salary' (Veneri 1999:15).

How do we know whether or not there is a shortage?

From the academic studies in the 1950s that criticized the proponents of the shortage debate for a 'misunderstanding of economic theory as well as … exaggeration of the empirical evidence' (Arrow and Capron, 1958:292, see also Alchian *et al*. 1958, Blank and Stigler 1957); to more recent reports by the UK House of Lords whose review into higher education and STEM subjects concluded that:

> '…lack of data makes it very difficult to assess whether there is in fact a shortage of STEM graduates and postgraduates and in which sectors. This is critical because, if it is not known whether there is a shortage, remedial actions cannot be put in place' (Select Committee on Science and Technology 2012:6).

There have been conceptual, methodological and ideological obstacles to producing good quality evidence about whether or not there is a shortage or surplus of highly skilled scientists and engineers (see also Wilkinson and Mace 1973, Kastner 1972, US House of Representatives 1991, Committee on Science, Engineering and Public Policy, 1995). While it is perhaps unsurprising that predicting future supply and demand is an 'inexact science' (Lane, 1995:np), it is important not to underestimate the ideological threads that run through this debate: as Godin points out 'incomplete statistics never prevented people taking firm positions on scientific and technical human resources' (2002:3). This can be seen in the following quotations from prominent voices in the field:

> 'I can give you my own opinion as a result of my long experience and effort in this field, but I fear I cannot give you authoritative data with numbers because I have been unable to find such data; so I am sure that many of your witnesses will give you their opinions, as I am doing. I doubt if very many of them can give you facts or figures which most of us would like to have if they are available' (evidence given by Admiral Hoare to the House of Representatives 1959:839).

> 'The models used to project supply and demand for scientists and engineers have been subject to criticism. But most of the dispute turns on quantitative details rather than the fundamental conclusion, namely that unless corrective actions are taken immediately, universities, industry and government will begin to experience shortages of scientists and engineers in the next four to six years with shortages becoming significant during the early years of the next century' (Presidential address to the AAAS, Atkinson 1990:427).

> '…it would be unfortunate if "an erroneous impression [were] created on the basis of insufficient evidence that there is no shortage of scientists and engineers - a premise which, in my judgment, would be injurious to the best economic and defense interests of the United States" (comments by AT Waterman, first director of the NSF, made in response to the publication of Blank and Stigler's 1957 book which disputed the existence of science and engineering shortages, cited in England 1982:405)

Despite this evident need for sound data on the STEM workforce, there are no specific sources of data on occupational shortages (Veneri 1999) and instead analysts have adopted three main approaches to estimating the supply and demand of scientists and engineers: demand forecasting, wage differentials and employer estimates. The advantages and disadvantages of each are considered in turn below.

Demand forecasting approaches

Over the period considered in this paper, the most widely adopted approach to estimating future supply of science and engineering workers by government agencies has been the use of demand forecasting techniques. This has usually involved projecting future personnel requirements from an assessment of demographic changes alongside projected throughput from education. This is then followed by estimates of the likely subsequent impact of these potential new graduates on the labour market (National Science Foundation 1961). It is a technique that was widely used during the post-War days of the shortage debate when concerns about science and engineering manpower were the 'primary impetus behind the orgy of forecasting which took place in the UK' (and the USA) (Mace and Taylor, 1975:177). Demand forecasting approaches were also used by the NSF in their series of, now discredited, working papers that predicted a shortfall of 675,000 scientists and engineers in the late 1980s (described in some detail above).

However, despite their widespread use, demand forecasting approaches have been treated with scepticism by economists and widely dismissed by labour market analysts. Criticisms have centred on the weakness of the technique in providing accurate assumptions about future changes to productivity and technology (for example, Hansen et al., 1967, Blaug 1966, Kastner 1972, Meager 1986, Lane 1995). Throughout the literature on the shortage debate, work on demand forecasting has been criticized for being of 'limited value' (Mace and Wilkinson, 1973:123), for not providing 'reliable estimates of future manpower needs' (Mace and Taylor 1975:175) and generally for being so 'chancy as to be intellectually disreputable' (Holloway, 1973:378). It is important to note, however, that many of these concerns are still relevant today (Teitelbaum 2014)

Analysis of wage differentials

As discussed above, labour market economists have taken a somewhat different approach to understanding whether or not shortages exist. Their approach has been based on examining 'the functional relationship between net demand and personal earnings from employment' (Wilkinson and Mace 1973:106) or, in other words, defining a shortage as 'an excess of demand for manpower at salaries paid by firms for similar manpower in the past' (Richardson 1969:53).

The basic premise is that if an employer cannot appoint at a going salary they must pay a higher wage and in doing so would have to decide whether the benefit accrued from paying the higher salary was worth the expenditure (Alchian et al., 1958, Richardson 1969). Subsequently, and in order to appoint suitably qualified workers, salaries would have to rise. But as Weinstein (2002) has argued, if there was a labour shortage all employers would experience the same issue and salaries would increase quickly across the sector, and more quickly than in other areas, in order to draw more talent into the field. So if earnings responded to competition in the labour market, more competition for jobs would lead to salary increases; although this process would necessarily take time. This time lag is inherent in how the market works and would be necessary to stimulate the market's response, so in the short term increased demand may not be accompanied by increase in salaries (Wilkinson and Mace 1973, Arrow and Capron 1958, Kastner 1972, Alchian et al., 1958).

However these assumptions would only hold if the market behaved competitively, as Weinstein argues: 'long term labour shortages do not happen naturally in market economies' (2002:2). But if wages were kept artificially low (for example by government intervention and budget controls) then shortages may occur and employers may find it difficult to get suitably skilled employees (Wilkinson and Mace, 1973, Cmd. 6824, 1945). However economists argue that this effect tends to be localised (either geographically or within a particular specialized industry) and would not be apparent across the whole of the economy (but see discussion on immigration later). They also argue that there is no evidence to suggest that scientists and engineers behave any differently in the labour market than other professionals, in terms of mobility and patterns of employment (Blank and Stigler 1957, Richardson 1969). This means that research that shows how the labour market responds to variations in supply and demand in other sectors would apply equally to the engineering and scientific workforce.

So from the economists' perspective, a shortage exists if and only if relative wages were rising over a prolonged period as employers increase salaries in order to attract suitably qualified workers (Meager 1986, also Blank and Stigler 1957). Therefore in the engineering and scientific market a steady upward shift in demand over a period of time will be likely to produce a shortage or a situation where there are unfilled vacancies in positions whose salaries are the same as those currently being paid to other workers of the same type and quality. The size of this shortage would depend on the rate of increase in demand, the reaction speed of the market and how responsive the mechanisms of supply and demand were to price changes (Alchian *et al*., 1958).

It is worth noting however, as Weinstein (2002) has pointed out, that labour shortages can be a positive factor in reducing employment inequalities because they make, in this case, government, university and industrial employers compete for employees. While this might be of concern for the sector, for the employee it requires employers to provide training and retraining, as well as salary and benefit increases.

Employers' estimates of shortages

> 'When one talks about scientific requirements of the country and makes them synonymous with the demands of industry, one has to find out how those demands of industry are built up. We have discovered in our successive enquiries that one of the least reliable ways for finding out what industry wants is to go and ask industry' (Sir Solly Zuckerman, oral evidence provided to the Robbins Committee, Cmnd. 2154, 1963:432).

Employer based approaches to estimating shortages have tended to adopt one of four methods of data collection: postal surveys, postal surveys plus (often telephone) interviews, interviews only and finally those that are based on case studies (Meager, 1984). Forecasts of supply and demand in the science and engineering sector in the 1950s and 1960s were frequently augmented by manpower surveys that attempted to predict supply and demand three or more years hence (e.g. Wilkinson and Mace (1973); see also Teitelbaum (2014)). These forecasts were often based on employers' estimations drawn from questions that are similar to the following:

> 'Do you expect to be able to recruit sufficient suitably qualified engineers, IT staff and technicians to meet your needs over the next 4 to 5 years?' (IET 2013:21)

This means that forecasts tend to be based on employers' current workforce plus their estimations about additions to this workforce over a future time period. According to Meager (1986) these approaches consistently resulted in predictions that demand would exceed supply. Indeed using employer estimates to predict demand in the sector has been widely criticized. For example, in the USA both Blank and Stigler (1957) and Alchian *et* *al.*, (1958) were concerned about the use of employer estimates, often undertaken by organizations such as the NSF, because of their poor response rates and lack of coherent definitions of the term 'shortage'. In his overview of employer-based projections in the UK, Meager (1986) cautioned against diagnosing a shortage in a particular market based on employers' reported recruitment difficulties. Few studies go back to check the reliability of employers' forecasts but, despite issues with the methodology and reliability of employer surveys (e.g. Adecco 2013, CBI 2013, CBI 2014, IET 2013), they often have high impact in informing policy decisions (e.g. Cmd. 902, 1959, House of Commons 2013).

One of the main issues with employer estimations is the risk of excessive generalizations based on a limited number of cases where employers may extrapolate their own experiences to the national level and *vice versa*. Employers may report difficulty in recruitment for a particular post, in particular locales or specialized disciplines that may be wholly internal to the firm and bear little resemblance to any shortage at an aggregate level. From the employers' perspective a shortage may mean 'any vacancy impeding production' (Meager, 1986:240) and therefore in itself is a poor basis for policy action (see Teitelbaum (2014) for a more recent account).

As this section has shown there is little consensus about the most effective and efficient ways to reliably predict future demand of scientists and engineers. A key obstacle to this is conceptual - that employers are concerned with numbers of employees while economists are concerned with wage trends – but this, coupled with ideological and methodological difficulties, has meant that many of the challenges to obtaining good quality evidence about the nature and extent of any shortage as are relevant today as they were 70 years ago.

The consequences of seven decades of 'shortages'

> '…despite no proven causal link between reported shortages and poor industrial performance, committees have been formed, research commissioned and training initiatives funded' (Meager 1986:236)

The consequences for the scientific and engineering sector of seven decades of debate and conjecture cannot be underestimated. In many ways this focus on human resource supply has been very positive for the sector, and arguably for wider society too, and has resulted in increased expenditure on research and development and more funding for science and engineering education programs at both compulsory and post-compulsory levels (e.g. Cm 8980, 2014). But some commentators voice concern that policymakers' responses to the cycles of 'alarm, boom and bust' that have characterized the debate over the last 70 years have had a detrimental and destabilizing effect on scientific development more widely (Teitelbaum 2014, Stokes 1997).

The immigration of highly skilled workers

One important consequence of a perceived shortage of domestic scientists and engineers has been an increase in the demand for foreign-born workers, with countries such as the UK and the USA adopting a variety of measures to attract migrant scientists and engineers from the global market (e.g. Parliamentary Office of Science and Technology 2008).

In the United States, a major consequence of the National Science Foundation's mid to late 1980's projections of an impending shortfall of 675,000 highly skilled scientists and engineers was an industry-led campaign to establish a new category of temporary visas for highly skilled overseas workers. These were subsequently introduced as part of the 1990 Immigration Act (Salzman *et al*., 2013, Weinstein, 2002, Matloff 2003). This visa, known as the H1-B temporary visa for specialist workers, has been a particular source of controversy. Although notionally intended to recruit the 'brightest and the best' highly skilled scientists and engineers from overseas, the only requirement for eligibility is that a prospective worker is educated up to the level of a US bachelor's degree or has equivalent experience.

The 1990 Immigration Act limited the number of H1-B visas awarded each year to 65,000. Subsequent attempts to expand the program, particularly by the tech industry, have led to increases in the number of visas awarded. In 2012, 262,569 petitions for H1-B visas were approved by the U.S. Citizenship and Immigration Service (USCIS). Around half were for continuing, rather than new, employment, with the majority of petitions coming from India and from people aged 25-29. Just under half of applicants who successfully petitioned had qualifications no higher than a bachelor's degree; just 8% of successful applicants had doctorates (USCIS 2013). The use of H1-B visas has been a particular issue for computer science occupations and 2012 USCIS data shows that 154,869 petitions were awarded in computer related occupations (mostly in systems analysis and programming), representing an increase of 15% over the previous year (USCIS 2013).

The temporary H-1B visa does not require any attempt by the employer to test the local labour market or to hire a domestic worker, requirements that are often widely misunderstood by commentators in this area (Teitelbaum, 2014). Assessing the advantages and disadvantages of increasing the numbers of foreign-born scientists and engineers to make up a shortfall in the supply of native workers is not straightforward.

The basic arguments run as follows. On the one hand, attracting highly skilled and motivated scientists and engineers from around the world would provide benefits for the organizations that employ them, as well as for wider society who would benefit from the advancements to which their expertise had contributed. But this comes alongside concerns that scientists and engineers from lower income nations, such as India and China, would depress local wages and that this would, in turn, discourage domestic talent from participating in scientific and engineering careers (Fechter and Teitelbaum 1997, Weinstein 2002, Salzman *et al*., 2013). One consequence of this would be poor career structures and a lack of stability and low wages that could result in an 'internal brain drain' away from STEM occupations (Matloff 2013:4, Nature 2011, Weinstein, 2002). As Matloff (2003) has argued:

> 'The H-1B program has a long history of abuse by IT employers of all types and sizes. The abuse is largely, but not exclusively, due to the de facto indentured servitude of the H-1Bs' (99).

In 2012, Microsoft, in projecting an annual recruitment shortfall of 120,000 computing occupations, recommended to Congress that it act to address the 'shortage' of STEM workers by making 20,000 new H-1B visas available each year for employers who hire foreign STEM graduates from US universities (Costa 2012). But in reviewing the evidence for Microsoft's claims, Costa (2012) found that the unemployment rate for computer related occupations was almost twice what it ought to be if these labour markets were at full employment. He also noted that wage trends for the sector (which would be expected to rise sharply in a shortage situation) had risen only very slightly between 2000 and 2011, further questioning the validity of any shortage claims.

The existence of short-term shortages

With the attention of the scientific, education and policy community focused on concerns about widespread and sweeping shortages across the sector, which as discussed here, have often failed to materialise. There has been little room for scrutiny and planning for short-term specialist skill shortages. For instance, some evidence does point to certain contexts in which science and engineering shortages *may* be apparent but this evidence also shows that such shortages can be limited to particular periods of booming expansion, to certain disciplinary specializations that have moved in and out of favour and to specific geographic locations (such as the concentration of tech employers in Silicon Valley) (see also UKCES 2013).

For example, in the early 1970s rising oil prices led to an expansion in research and development within the industry and a subsequent increase in demand for petroleum scientists and engineers (Teitelbaum, 2014). However, by the early 1980s falling oil prices were accompanied by a decline in industry investment and lowered demand for skilled workers. This meant that what were once good job prospects had now deteriorated and in consequence there were fewer new entrants to what had become a contracting sector. From the start of the new millennium onwards, rising oil prices combined with the emergence of new technologies, such as 'fracking', once more resulted in increased demand for scientists and engineers with skills in this area. But as it takes time to recruit and train these workers, a sudden boom in the industry is necessarily accompanied by a time lag before the education system can supply workers with the required skills.

There are parallels here with the nuclear power industry. In the late 1970s and early 1980s enthusiasm for nuclear power had started to decline, in part influenced by low oil prices but also by accidents at Three Mile Island, and later, Chernobyl. Demand and career prospects for nuclear scientists and engineers diminished as a result. However, more recent rises in oil prices, instability in the Middle East and targets for reducing CO_2 emissions have led to renewed focus on nuclear power. So after two decades of little or no demand for nuclear scientists, workers with the necessary and specialized skills were once more needed and concerns about skills shortages in this field were raised (e.g. Cm. 8980, 2014). However, the 2011 accident at the Fukushima nuclear plant in Japan has prompted some wariness over future investment in nuclear power, which in turn could have a potential impact upon the training and recruitment of highly skilled workers in the nuclear industry (Schneider 2011).

These two examples from the energy industry provide a useful illustration about how difficult it is to plan and forecast future demand of skilled workers in a specialized industry. Economic, geopolitical and social changes mean that workforce forecasting cannot be based only upon birth rate projections and anticipated throughput from education. However such 'pockets' of shortages may be transitory and can be difficult to predict (UKCES 2015). For example, a 2015 report into skills shortages within the pharmaceutical sector points to some of the challenges in addressing these 'pockets' of shortages (APBI 2015). This report is presented as a follow up to a 2008 document that identified skills gaps in areas such as drug metabolism, pharmacokinetics and in vivo sciences. However in the later report, shortages in these areas were found to no longer exist. Partly, the report claims because of new initiatives that were funded in response to the earlier shortages but also because of 'the changing landscape of the pharmaceutical industry' (APBI 2015:6). While both explanations may be true, the transitory nature of these shortages makes it very difficult for educational institutions to respond, as is so often requested, with new programmes and more specialised training, to what might be a relatively short-lived skills deficit. Notwithstanding the implications for new students who may have been recruited to these shortage areas and who, while still inside the

STEM education pipeline, might find themselves qualified for specialist work in areas where there is no longer much demand for their skills.

Summary

> '…no science and technology statistics have caused more debates and controversies than those on human resources' (Godin 2002:29).

The arguments presented in this paper have been guided by five questions about the longevity of the science and engineering shortage debate in the UK and the USA and the role this has played in shaping science education policy over the long term. A number of key findings have emerged. First that concerns over shortages of suitably qualified scientists and engineers are nothing new and have existed since at least the time of the Second World War. Secondly that the levels of concern have risen and fallen in line with global events that have largely been related to issues of national security and economic growth such as the launch of Sputnik in 1957 and the economic success of Japan in the early 1980s. Each cycle has been characterised by demands from employer organisations, government departments and the education sector for further investment in scientific education and training in order to meet projected shortfalls in the numbers of suitably qualified STEM workers. The reasons provided for these apparent shortages have remained remarkably similar over the period: insufficient numbers of young people studying key subjects at the highest levels, the poor quality of school science teaching and insufficient numbers of well qualified science teachers. Remedies have tended to involve requiring more young people to study science through compulsory study at school or initiatives intended to encourage participation in science and engineering education or careers, often at considerable expense to the taxpayer. A third finding shows there is no consensus view about the existence of a skills deficit. Ever since the time of Sputnik, claims of shortages by the sector have been matched by counterclaims by labour market economists and other analysts that there is little evidence of sustained and long-term shortages in the sector. Finally we have seen that the shortage debate is underpinned by methodological and conceptual shortcomings that leave the veracity of the deficit claims in doubt.

Although these shortage claims have frequently been challenged, the rhetoric contained in these accounts of a crisis in science and engineering recruitment is strong (see for example the language used in the *A Nation at Risk* report) and persistent and has succeeded in becoming the dominant political and public view. As a consequence, alternative accounts are largely absent from wider discussion which, in turn, has served to 'confuse serious thinking and to distort public policy' (Teitelbaum 2014:26). As the economist Paul Krugman has argued: the purported skills gap is ‘a prime example of a zombie idea - an idea that should have been killed by evidence, but refuses to die’ (Krugman 2014:A21).

Discussion

So what can we conclude from this discussion of the wider historical context of the science and engineering shortage debate? As summarised above, although the shortage debate has a long history, it is one that is characterized by poor quality data, methodological and conceptual challenges. But this is a debate that continues in the UK and the USA, as well as in many other countries (e.g. Shah and Burke 2003, Gago et al., 2004), where concerns about the relative decline of science and engineering in their respective nations have tended to follow the same trajectories of ‘alarm, boom and bust’ (Teitelbaum 2014) described here.

Seven decades of a purported shortage crisis have resulted in repeated calls for action from influential national figures to increase the flow of, usually, graduates into science and engineering fields. But the evidence presented in this paper suggests that while there may have been short lived shortfalls in specialist areas (such as within the energy industry), there is no evidence in support of widespread and far reaching shortages as the rhetoric claims, and little to indicate that if there were any shortages that they have been sustained and far reaching (see also Weinstein 2002).

So why has this myth persisted for so long and with such potentially destabilizing consequences for the sector? One of the answers lies in conflicting views of how the labour market operates and in particular how the term shortage is interpreted, whether it be a shortfall in numerical supply (i.e. enough people to do a job) or related to an employer’s requirement for lower cost employees. These different conceptions of what constitutes a shortage have been central to many of the claims and counterclaims that have come to characterize this debate. But there are other reasons as well. Many of these are related to the, often inadequately explained, methods used to gather and interpret data on workforce supply and demand. Such analysis is not straightforward and difficulties with definitions and data have been central to shortage controversies in other areas such as the medical and the teaching profession. As this paper has shown, the use of different and often inadequate definitions of occupations and qualifications have often been combined with confusion over the relationship between the two. There has also been an over-reliance on techniques that involve projecting past trends to the future and an uncritical acceptance of employer estimates of future shortages. All these problems have resulted seventy years on in there being still no widely accepted way of compiling reliable data on workforce supply and demand.

Without wishing to stray into conspiracy theory, maintaining accounts of a 'crisis' in the supply of STEM workers has usually been in the interests of industry, the education sector and government, as well as the lobby groups that represent them. Concerns about a shortage have meant the allocation of significant additional resources to the sector whose representatives have, in turn, become powerful voices in advocating for further funds and further investment. Their arguments for increased investment and the reform of science and engineering education and training have tended to be as follows. First, as the potential for scientific discoveries is unlimited (which for many is a good thing), there should be a continuous increase in the supply of qualified personnel. Second, market forces are not able to deliver resources in sufficient quantity or quality to meet national needs and that as a consequence government should secure finances to provide the *right* number of scientists and engineers (Godin, 2002). To demand more scientists and engineers is, to some extent, in the interests of wider society as well. A larger pool of workers and more funding could mean further, faster and cheaper advances in medical, technological and other fields. But there are also human and ethical costs in using a shortage debate to encourage students to study science and engineering at undergraduate and graduate level (while incurring considerable debt) many of whom face little prospect of stable and rewarding careers in the field.

There are implications here for science education policy as well. While in many ways STEM subjects have benefitted enormously from the enhanced status and increased funding afforded to them by the skills shortage claims, there are downsides to this. On the one hand there are the ethical implications for future employment as mentioned above, but there are also implications for the nature of science education itself. At the start of the paper, I referred to the dual purpose of science education and the tensions that this can sometimes create between 'science for all' and a much more instrumental view of science education for economic benefit. It is perhaps pertinent to consider which is more desirable: the science of accountability measures where national curricular are aligned with international comparative tests, that have little to do with the national context, so that governments can better monitor and compare scientific education with that of their closest economic competitors. Or a science curriculum based on enlightenment models of learning driven by a 'spirit of rational inquiry… a belief in its efficacy and by restless curiosity…a spirit of science' (Educational Policies Commission (1966:1). Proposals by the British Department for Education to align curriculum content with the knowledge and skills that are assessed as part of international comparative tests perhaps provides a partial answer to these questions (Department for Education, 2011).

The arguments presented here lead us to several suggestions for what should happen next. First, workforce planning for the sector needs to be based upon the best quality data available, rather than upon hearsay. Secondly, decisions to invest in the sector should not be made in response to short term fluctuations in supply that affect only specialized areas and yet are, more often than not, projected to the wider STEM workforce. There also needs to be recognition that changes in demand in specialized fields can be sensitive to what happens beyond the sector. Therefore particular attention needs to be paid to the wider political and economic context and that any fluctuations in the STEM job market may be short term and require targeted and focused, rather than wider, intervention.

Finally to bring the discussion fully up to date, let us turn to the two recent reports on the STEM workforce published by the US and the UK governments. *Engage to Excel* was published by the President's Council of Advisors on Science and Technology in February 2012 (PCAST 2012) and offers a strategy for improving STEM education. It claims that to meet future demand for highly skilled STEM workers the USA will need to increase the numbers of STEM graduates by 34% each year and advocates a focus on pedagogic and curriculum development, and partnerships during undergraduate STEM programs. *Our plan for growth: science and innovation* was published by the UK Department for Business Innovation and Skills in 2014 (Cm 8980, 2014). It points to the need for the education system to respond to shortages of skilled and well-educated people in STEM subjects that employers hold in high demand and pledges £67million of new programs to increase the quality of science teachers in schools. The 'shortage crisis', it seems, is set to continue.

Notes

[1]The nomenclature used to describe science and engineering subjects has varied over the period considered in this paper, from science and engineering (S&E); to science, engineering and technology (SET) to science, technology, mathematics and engineering (STEM). Where possible we have used the terms that best reflect those in use during the particular period being discussed.

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