The Benefit of STEM Skills to Individuals, Society, and the Economy

Report to Royal Society's Vision for Science and Mathematics

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Executive Summary

- There are good reasons for thinking that education causes worker productivity to rise through the acquisition of new skills and that, in a market economy this gets reflected in wages to the benefit of the individual concerned. Whether there are wider benefits, apart from the private benefits to the individual concerned, is less well researched. This report considers the extent of private and social benefits associated with STEM (science, technology, engineering and mathematics) skills.

- We find convincing evidence, from a Danish reform, that mathematics skills acquired at school are important – they have a causal effect on later earnings that are large – perhaps as large as 10%. Moreover, correlations for the UK suggest something similar and these results seem to be robust to including a range of additional controls.

- The development of STEM skills at school are important – not least because they are a prerequisite for selecting STEM higher education (HE). But it is unclear whether the earnings premia associated with STEM subjects in higher education reflect pre-existing skills, or the skills acquired in HE.

- The earnings premium for HE, on average, seems large. This is consistent with the view that there is too little HE. The evidence points to there being a greater than average earnings premium for STEM which would be consistent with this shortage being more acute for STEM.

- There are several studies that show that earnings premium for STEM degree subjects, on average, are large relative to Arts and Humanities and Social Studies, but not relative to Management/Law/Economics. However, it is unclear how much of these differentials could be due to differences in ability.

- The earnings premium for a degree has risen in the UK over the last three or four decades, similarly to US evidence. Even the large expansion of HE in the early 90's does not seem to have driven the return to fall significantly. The most convincing explanation for this rising trend is that *skill biased technical change* (SBTC) has proceeded at a faster rate than the rising supply of graduates.

- The importance attached to the role of technology suggests that STEM might be particularly important. However, while SBTC features heavily in the literature on the graduate earnings premium, there has not been any investigation into how the relative returns to STEM vs non-STEM has changed over time.

- There is a suggestion that the biggest rises in returns has been seen at the postgraduate (PG) level. Surprisingly, the little evidence that addresses PG training does not suggest a higher return to STEM.

- There has been a small shift in student choices towards STEM that would be consistent with rising earnings differentials. However, any rise in differential has been small and, in any event, there is no convincing evidence that subject choices respond to their earnings differentials.

- There is convincing evidence that the effect of education on earnings is causal – the effect of education does not seem to work through signaling pre-existing ability in any important way. This is supported by macroeconomic evidence on the determinants of per capita income and its growth.

- There is also evidence of spillovers arising from HE. While little of this evidence specifically relates to STEM the work that does suggests that expanding the supply of STEM skilled workers could have important spillover effects. There is evidence that migration can relieve skill shortages and improve earnings of native skilled workers. Migration is a potential source of highly skilled labour. The dramatic recent growth of HE in China could make up for domestic STEM shortages should visa requirements be relaxed.

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Chapter 1 Background

1.1 Remit

This report reviews and evaluates the research concerned with the contribution of STEM (science, technology, engineering and mathematics) skills to individuals, and to society in general; identifies the shortcomings and gaps in the literature; and comments on the implications of our conclusions for future demand and supply of STEM skills.

There have been several reports that have collectively drawn attention to many of the issues here. In particular, our review builds on earlier reports that have considered the role of STEM and its constituents in the economy.[1] With the exception of Greenwood *et al* (2011) these reports do not contain original research but, rather, draw together the findings from existing research. The contribution of our review, relative to previous reviews, is that we bring together a much wider variety of evidence that all bears on a relatively narrow issue. In particular, we are much more selective in that we place much higher weight on research that helps us understand the *causal* effects of STEM, as opposed to what are merely associations in the data. Our conclusions are heavily driven by the best evidence rather than by consensus built around correlations. We explain our methodology in more detail in Chapter 2.

1.2 Overview

There is widespread agreement that human capital is one of the most important determinants of the differences in the growth in per capita incomes and their growth across time and countries. It is thought that the *level* of educational attainment has a *causal* impact on real incomes at the individual level. At the aggregate level this is then reflected in per capita income at the country level – indeed the aggregate effect may exceed the average individual effect since the latter ignores spillovers from the education of one individual on the productivity of other individuals. Indeed, there is some theoretical suggestion that education can affect the *rate of growth* in real per capita income at the aggregate (country) level. This is also a form of spillover: education of the current generation might raise the productivity of future generations.

Moreover there is extensive evidence that the impact of education on real incomes is sensitive to the demand for and supply of skilled workers. Indeed, it is widely believed that in the "race between technology and education" it is education that is losing and the result is rising returns and widening inequality between highly skilled labour and the rest.

The idea that technological developments have driven up the demand for skilled labour is known as **skill-biased technical change** (SBTC) and this has been quite

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[1] Greenwood, Harrison and Vignoles (2011) is notable for containing new evidence regarding the earnings of engineers - see http://www.engineeringuk.com/research/engineering_uk_report/. The Institute of Physics (2012) is a description of the role of physics in the economy but with no consideration of the causal relationships involved - see http://www.iop.org/publications/iop/2012/file_58713.pdf. The Deloitte (2012) is a similar description of the role of mathematics but with no consideration of the causal relationships involved - see http://www.epsrc.ac.uk/SiteCollectionDocuments/Publications/reports/DeloitteMeasuringTheEconomicsBenefitsOfMathematicalScienceResearchUKNov2012.pdf. The review by Lord Sainsbury for HM Treasury (2007) ranges more widely over innovation issues - see http://webarchive.nationalarchives.gov.uk/+/http:/www.hmtreasury.gov.uk/d/sainsbury_review051007.pdf.

successful in explaining the growth in the demand for skilled labour in the past few decades. However, there is considerably less evidence on how the composition of the stock of human capital affects the level of individual incomes and the pace of growth in average incomes. Even though the world of work has rapidly become a much more complex place, largely driven by the fall in the price of computing power, there is little evidence that has addressed the extent to which this has affected relative incomes *within* the stock of graduates. For example, one might have expected technological change to have increased the relative demand STEM graduates. We have little hard evidence that student choice of major has responded to this. Student choices seem to have changed relatively modestly over time. This is surprising given the widespread agreement that it is technology that has driven the growth in real incomes, at least in developed countries.

That investments in human capital affect productivity and that this is reflected in wage rates is well accepted. That is, there is a **private** return to human capital investment – it benefits the owner of that capital. Unlike physical investment ownership cannot be transferred – while a physical investment can be bought and sold in financial markets, human capital can only be leased from its owner via the labour market. The case for subsidizing such investments ultimately rests on arguments that there is too little of it. That is, the market mechanism does not, for some reason, provide the right incentives for individuals to make the right amount and type of investment in human capital; or, if it does, then individuals are not, for some reason, able to respond to those incentives. The case for subsidizing human capital in general, or some specific subject area, inevitably relies on a market failure argument.

Higher education stands on the shoulders of compulsory and post-compulsory further education. Education is progressive in most subjects and probably especially so in STEM subjects. Basic skills are essential for participation in society and we rightly encourage their development in everyone through compulsory education. Over time there has been an increase in the extent of these basic skills reflecting, in part, the greater complexity in society, and a matching rise in compulsory schooling. The argument for large subsidies for compulsory schooling is that the whole of society benefits from each individual having a basic level of skills. Thus, we analyse the evidence on the impact of technical skills, especially numeracy. Given the progressive nature of STEM subjects in particular, basic skills are especially important because they provide the foundation for further learning. Thus, any failure to produce basic technical skills will have longer run impacts on the accumulation of advanced STEM training.

The evidence of the effect of education on individual earnings is rich. We present evidence on the impact of basic technical skills, especially numeracy. Recent studies show that the wage returns for sub-degree level STEM qualifications could be quite substantial and STEM occupations (jobs) may have an additional premium. While a significant proportion of the long term effects of basic reading and mathematics skills (measured at age 10 or earlier) are thought to be mediated through the highest qualifications, there are important standalone effects of reading, and especially mathematics ability, on labour market outcomes.

More generally, by taking advantage of "natural experiments" and other evaluation methods and using better quality data (e.g. evidence from data on twins and using data drawn from population administrative registers), labour economists have managed to estimate the private return to one extra year of schooling with reasonable precision. The point estimate is found to be in the range between 5 and 15 percent, depending on time and country – that is, increasing an individual's schooling by one year raises income by between 5 and 15%. There is also evidence that this return has been growing over time.

There is general agreement that SBTC is responsible for the growth in the returns to education, and the consequent increase in income inequality, that has occurred in the US, the UK and many other places over the last three or four decades. The importance attached to technology in this theory suggests that STEM education might play a dominant role. Indeed, the SBTC theory might suggest that the returns to computer literacy would have risen over time. Few studies examine this issue, largely because such skills are seldom recorded in large sample surveys. Krueger (1993) is an early exception. Studies in the UK of this phenomenon are also scarce but a notable contribution is Dolton and Makepeace (2004).

There is only limited evidence of **rises** in the returns to STEM degrees **relative** to other majors, or of changes in student choices of majors over time towards STEM that may be a response to rising returns and emerging shortages. However, the failure to distinguish between STEM and non-STEM is common in the literature and we are still a long way away from being able to draw policy conclusions regarding the causal effects of specific majors. This is not surprising since, while it is clear how one might estimate these causal effects across subjects, the data requirements preclude this in most countries. The case for subsidizing HE in general, and STEM HE in particular, rests not on the private returns but on social returns. These come in different forms: **productivity externalities** are based on the idea that social interactions on-the-job create learning opportunities for everyone; while non-economic spillovers are based on the idea that HE enhances other aspects of behavior that are valued by society – voting, charitable giving, and abiding by the law are possible examples. These literatures are thin and only a few of the most recent studies make a distinction between STEM and other majors. The limited empirical evidence suggests that the social returns to higher education might be substantially greater than the corresponding private returns, although one should be cautious not to draw strong conclusions from a handful of studies, most of which are from the US. We also consider the non-economic returns to acquiring higher education. The small literature that has only emerged over the last decade points to a positive effect of education on such diverse outcomes as political participation, social trust, and financial literacy which, in turn, increases savings and improves retirement planning. However, again, much of the literature fails to highlight a particular role for STEM as opposed to education in general.

Finally, while the existing literature has focused on STEM in HE it has done so largely at the undergraduate level. Again, very few studies cast light on postgraduate education. Three notable exceptions are recent work by Lindley and Machin (2011) and Walker and Zhu (2011), and much older work by Dolton *et al* (1990) for the UK.

Chapter 2 Method

A search of the major databases for literature published since 1990 was conducted. We considered only: studies published in the English language; in physical books or peer reviewed journals (either internet-only or physical publications) or in working paper series listed in IDEAS (http://ideas.repec.org/) and available for download; containing an abstract; were original studies (we excluded reviews); and were conducted in developed countries (to limit cultural differences). In addition, we attempted to isolate studies that directly addressed STEM, either collectively or separately. However, this was a small set and, where we think it relevant, we also refer to studies that simply report the average across subjects. For example, if we consider a paper was making an important generic contribution then we included it in our analysis.

From this extensive literature we selected for "quality" on the basis of our professional judgment. This was partly based on the originality of the work, but mostly on the extent of its relevance for UK policy, and particularly on the extent to which the methodology used could be used for making causal inferences. In particular, since we were concerned with drawing out policy inferences, we filtered for studies that we felt made some concession to the need to provide more than simple correlations to address, at least in part, the extent to which results might be contaminated by confounding factors. We also required that the sample sizes be large enough to provide the statistical power to address the issues we were concerned with, and that sufficient evidence was provided to demonstrate the statistical significance of findings. Replicability was not a criterion that we felt appropriate to apply because the literatures that we were examining did not come from a culture where great weight is attached to replication. In each area of concern for us we have been heavily influenced by a small number of studies that we felt were of high quality. An overriding consideration for us has been to emphasise evidence on the importance of causal effects, rather than simple correlations, that seems likely to be useful for policy.

Chapter 3 Findings in the Literature

Education is progressive in most subjects and probably especially so in STEM subjects. Moreover the basic skills of literacy and numeracy are essential for participation in society and we rightly encourage their development in everyone through compulsory education. Over time there has been an increase in the extent of these basic skills reflecting, in part, the greater complexity in society, and a matching rise in compulsory schooling. The argument for free (or, at least, highly subsidized) compulsory schooling is that the whole of society benefits from each individual having a basic level of skills, not just each person individually – the benefits of being able to read is higher the more other people can read and write. If it were left to each individual to invest in such basic skills they would give too little weight to the effect of their basic skills on the returns to others. Moreover, there is considerable evidence that individuals are "time inconsistent" in their behavior and so procrastinate - but when it comes to the acquisition of basic skills postponement makes their acquisition more difficult for developmental reasons. So such time inconsistency would be an additional reason for subsidy and/or compulsion.

Below we present the evidence on the impact of basic skills, especially numeracy. Given the progressive nature of STEM subjects, these skills are especially important because they provide the foundation for further learning. Thus, any failure to produce basic technical skills at an early age will have longer run impacts on the accumulation of advanced STEM training (and probably non-STEM training to an extent).[2] Thus, we also consider the impact of basic skills on later achievement and selection, and thence on earnings. For example, in the UK literature such skills would be measured by early test scores in surveys, or from Key Stage (KS) 1, 2 and 3 achievements at ages 7, 11 and 14 in administrative records. Later achievement would be measured by national examination achievement scores at 16 and 18, usually captured by GCSE and A level attainment in England and Wales (and by similar qualifications in Scotland). After 16 in the UK (slightly less so in Scotland) there is extensive selection that results in specialization at an early age relative to most other countries. Given the progressive nature of STEM subjects, in particular, such specialization at an early age not only reduces the average level of achievement in subjects which are dropped beyond age 16, but it may also destroy "option value" – the value associated with keeping one's options open until a later date. The extent of the long term effects of earlier mathematics/science attainment on earnings will depend on how those choices at 16 determine choices of study in HE - since this will affect the supply of graduates of different types into the labour market which ultimately determine graduate earnings differentials.

3.1 Sub-HE STEM

3.1.1 Basic skills

A recent US Brookings report (Rothwell, 2013) estimated that 20% of all jobs in the US as of 2011 require a high level of knowledge in at least one STEM subject. Half of US STEM jobs are at the sub-bachelor's degree level, and with an estimated 10% wage premium compared to non-STEM jobs with similar educational level

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[2] We are not concerned here with pedagogy or specific course content. See National Research Council (2011) for the US, and the work of the National Curriculum STEM Centre at http://www.nationalstemcentre.org.uk/stem-in-context/curriculum for the UK.

requirements. Greenwood *et al*. (2011) is the most up-to-date report on the UK labour market value of STEM qualifications and occupations. Compared to the 20% share of STEM jobs in the US, only 12.3% of all jobs in the UK in the pooled Labour Force Survey (LFS) 2004-2010 were classified as STEM, even with their broad definition. They find that many STEM subject qualifications carry a wage premium, especially for engineering subjects. Some STEM qualifications also have considerable additional wage premium if used in a STEM job.

School education is a cumulative process, in the sense that the most important determinant of the academic performance of a child at any time point is prior academic attainment. Duckworth and Schoon (2010) uses the data from the Avon Longitudinal Study of Parents and Children (ALSPAC) to show that the correlation between KS2 Mathematics and KS1 Mathematics is 0.66 while that between KS2 English and KS1 English is 0.67. Their focus is on the role of non-cognitive skills and they show that these strong correlations are somewhat diminished, but still remain highly significant, when non-cognitive skills are controlled for. The suggestion with this latter observation is that correlations in the raw data are likely to reflect the importance of these non-cognitive skills for cognitive achievement at all levels. In other words, these correlations do not tell us the effects of raising achievement at one level on achievement at a subsequent level because part of this arises through correlations with non-cognitive skills.

Several studies highlight the predictive power of achievement at the end of primary school, around age 11, for a broad range of successful outcomes in adulthood (see, for example, Feinstein and Bynner, 2004). Parsons and Bynner (2005), using the 1958 and 1970 birth cohort studies, show that poor literacy and poor numeracy, as measured at age 37 for children followed from birth in 1958 in the National Child Development Study (NCDS) and at age 21 and 34 for the children followed from birth in 1970 in the British Cohort Study (BCS), are not only associated with early school leaving and low qualifications but they also have a strong adverse effect on life chances at age 30, including employment, benefit dependency, home ownership, civic participation, health and self-esteem. Although they do not directly analyze the effects on earnings, many of the things that they do measure will be reflections of earnings differentials.

Moreover, they show that poor numeracy is more important than poor literacy that determined low economic well-being. Bynner and Parsons (2006a, 2006b) further demonstrate that the children of parents with poor literacy and numeracy are seriously disadvantaged, regardless of the level of parental qualifications. It is very clear in this work that causality is an issue since skills are being measured in adulthood. Thus, they go on to estimate that *changes* in the level of basic skills are associated with *changes* in life chances. However, even here, the direction of causation is not clear.

Controlling for unobservable conflating factors, such as non-cognitive skills, is a difficult challenge for researchers. Using differencing techniques, such as in the Bynner and Parsons example above, is likely to be unconvincing because of the strong persistence in basic skill levels – these skills are easiest to acquire at an early age for developmental reasons so their level at an early age is usually a very good reflection of their level later. Indeed, a great deal of research supports this idea. Most notably, Nobel laureate James Heckman has shown, in many papers, that interventions early in the life cycle of disadvantaged children have much higher economic returns than later interventions such as adult literacy programmes.[3] Indeed, his work supports the idea that lifecycle skill formation is dynamic in nature. In his words …. "Skill begets skill; motivation begets motivation" so that a child who is not motivated to acquire basic skills early in life is more likely to fail to be socially and economically successful in later life.

Vignoles *et al.* (2011) estimate the wage return to both literacy and numeracy as measured at age 34 for the 1970 BCS in the 2004 labour market. BCS is the most appropriate dataset for work on this topic because, unlike the earlier NCDS, the tests were administered to the whole cohort (at 34); and unlike the International Adult Literacy Surveys (IALS), the survey is extensive in the background information that it collects. So this is probably the most comprehensive and convincing study for the UK amongst those studies that attempt to drive out the effects of confounding variables using a rich set of controls.

Adding a wide set of control variables can be thought of as driving out bias arising from contamination by these observables in the data, but it does not follow that it will necessarily reduce the bias associated with missing unobservable variables. Nonetheless, there is a good case for thinking that the method tightens the upper bound on the causal effect that such correlations provide. They find literacy and numeracy skills are positively associated with earnings, over and above the effect of education on earnings. Their preferred estimate suggests that a one standard deviation increase in adult numeracy results in 11% higher earnings (with a slightly *larger* effect for literacy). They also assess whether the wage return to skills has increased over time, and find that literacy and numeracy skills have retained their high value in the UK labour market over the period 1995–2004, despite numerous policy attempts to increase the supply of skills during this period that, if successful, we would have expected to lower returns.[4] This result is consistent with the widely accepted view that the *demand* for skills has been rising over time as well as their supply.

Crawford and Cribb (2013) use the 1970 BCS to study the relationship between weekly earnings and hourly wages at ages 30, 34 and 38 and reading and mathematics skills – but measured at age 10. They also adopt the idea of controlling for a rich set of demographic and family background characteristics, and they find that a one standard deviation increase in age 10 mathematics (reading) scores is associated with 10% (5%) higher earnings during one's 30s. Even controlling for the cohort member's highest educational qualification the effect of higher reading scores (during one's 30's) is around 2% and the effect of higher mathematics scores falls to 7%. This implies that around half of the long-term effects of earlier reading and about one third of the mathematics attainment effects are mediated through the highest qualifications. Nonetheless, there are still independent effects of reading and mathematics ability on one's labour market outcomes, especially for mathematics.

3.1.2 Technical skills

Autor, Levy and Murnane (2003) were among the earliest researchers to draw attention to the role that computers have played in the workplace. They consider how

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[3] Excellent summaries of these ideas in Heckman's work are in Heckman (2008) and Heckman and Kauz (2012).

[4] The Department for Education reports that the number of adult individuals with numeracy skills below the minimum target for 9–11 did fall from the 7 million estimated in 1997 to 6.8 adults in 2003.

computerization alters job skill demands. They find that within industries, occupations, and education groups, computerisation is associated with a reduction in the labour input of routine manual and routine cognitive tasks and the increased labour input of nonroutine cognitive tasks. This work has been further developed to suggest that the falling price of computer power, together with globalization associated with lowering costs of trade, have been responsible for the "hollowing out" of the labour market – those involved in routine work, often those in the middle of the labour market, who are associated with the production of tradable goods and services have found their jobs increasingly displaced by outsourcing and other changes in the location of production as well as by computerisation.

The increased skills associated with using a computer at work might be expected to be reflected in the wages of those with those skills relative to those without. Krueger (1993) has attempted to address this issue in the US, and Dolton and Makepeace (2004) in the UK. The difficulty here, as with literacy and numeracy, is the possibility of confounding variables. Krueger's paper sought to measure directly the impact of computer use on wages. He showed that individuals who used computers at work in the US received a wage premium of between 10 and 16 percent during the 1980s. Moreover, he found that between 1984 and 1989 the computer use wage differential did not decline, indicating that the demand for workers with computer skills may have shifted out as rapidly as the outward shift in the supply of computer literate workers. Krueger (1993) suggests that workers who possess unobserved characteristics that are associated with computer use at home may be selected by employers to use computers at work on the basis of these same characteristics. Therefore, holding constant computer use at home should reduce any bias in the returns to computer use at work.

However, Dolton and Makepeace (2004) correctly point out that individuals who use computers at work may be more able, in other dimensions apart from computer skills, than individuals who use computers only at home. So the Krueger estimates should be thought of an upper bound on the true causal effect. Dolton and Makepeace use UK NCDS data that records computer use at work and home. A wide set of controls for industry, occupation and background yield similarly large estimates as Krueger. However, estimates that exploit the effect of the acquisition of new computer skills across waves of the data are smaller and generally insignificant. Similarly, estimates that weighted the data to better match computer users and non-users were also generally smaller, although statistically significant. A reasonable conclusion is that there is a small causal effect of computer literacy on wages.

Of course, technical skills go beyond mere computer literacy and there is a widespread view that technical education more generally is weak in the UK. Technical education is often described as the poor relation of academic learning, and this has been widely recognized, not least by the government who is keen to promote STEM subjects, including at below HE level, and STEM careers. The recent Wolf review of vocational education (Wolf, 2011) suggested that between one quarter and one third of the post-16 cohort is receiving low-level vocational qualification, with little or no market value.

The causal effect of non-HE (further education) vocational education and training (VET) qualifications is a neglected topic. The heterogeneity in both the types of qualifications available and the routes that students take to and through them makes the analytical task here particularly problematic. One relatively clearcut and convincing attempt is Stromback (2010) that uses matching methods to compare the outcomes of Australian youths who pursue a school-based vocational course as opposed to an academic curriculum or who leave school early. The work supports some of the findings in Wolf's report for the UK in that it finds that a VET curriculum is estimated to have no significant effect on early career earnings.

3.1.3 STEM achievement at schools/FE

It is a widely held view that there is a significant mismatch between the projected employment requirement in the STEM industries and the domestic supply of individuals with STEM qualifications in the UK. One piece of evidence that may explain this is the relatively poor performance of UK's 15-year old pupils in Mathematics and Science in the OECD's PISA tests (which also covers reading). The UK's ranking from 2000 has been falling and in 2009 was just below the OECD average in Mathematics and slightly above in Science. However, England's ranking in the TIMMS tests (which have similar sampling methods but are at age 13/14 and cover different, but overlapping, pools of countries) trend in the opposite direction.

The focus of PISA is on being able to use skills in real life situations, while TIMMS is concerned with ability to meet an internationally agreed curriculum but it is unclear that this distinction is strong enough to explain the different trends. Nonetheless the relatively low and falling level of PISA achievement is a concern and has arisen despite the time allocated to STEM in the school curriculum shown in Figure 1. A key contributing factor to UK's STEM deficit is the very low GCSE science and mathematics achievements.[5] Not surprisingly, the UK has one of the lowest shares of 15-year olds intending a STEM career as shown in Figure 2.[6]

In 2011-12, 24% of pupils did not even attempt a science GCSE and just 49% achieved a pass in two sciences at GCSE which is a component of the *EBacc*, the new gold standard set by the government (Broughton, 2013). While Mathematics GCSE is compulsory as one of the core subjects alongside English, less than 50% of students have actually achieved grades A*-C in both subjects; and even at age 18 the figure is still below 50% (see Wolf, 2011). Of those with good science GCSEs, only one in five goes on to take Science A-Levels two year later.

Although the number of students taking A-Levels has risen since 2002, this growth is still very modest compared to the recent growth in Mathematics A level – although this was from a low base following the introduction of Mathematics AS which was originally found to be very difficult and resulted in mathematics at A-level being dropped by many students.

Quantitative skills at school plays an important role in subject choice in HE and hence on subsequent career options. Several subjects require A-level mathematics, and many more clearly select on it. Figure 3 below shows how the absence of A-level mathematics would narrow the range of options for study in HE.

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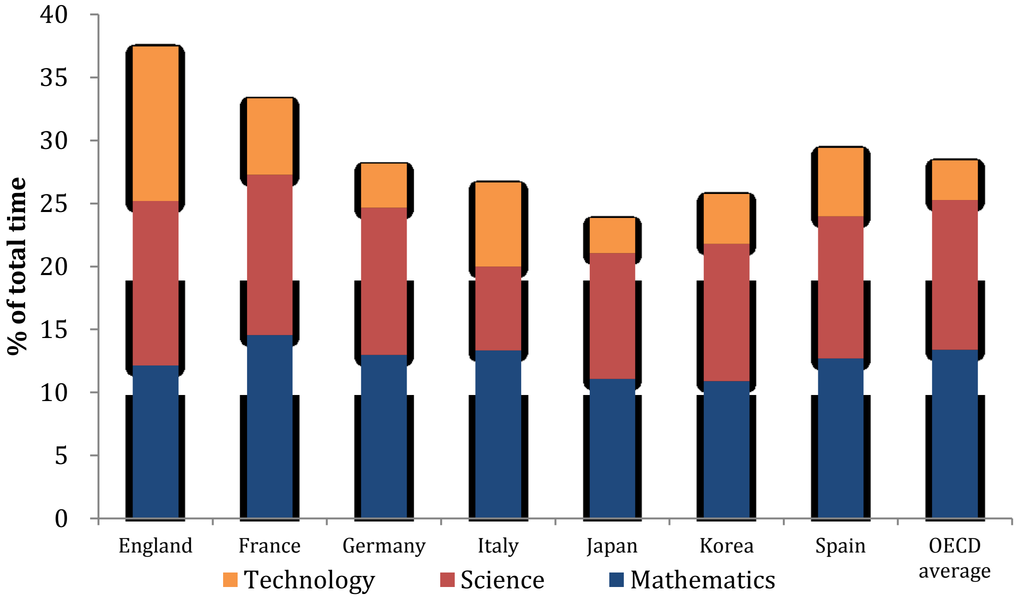
[5] Low scores in international testing studies are suggestive of a lack of achievement by international standards, and the requirement of GCSE passes in STEM subjects as a pre-requisite for further study will imply lower STEM participation beyond age 16.

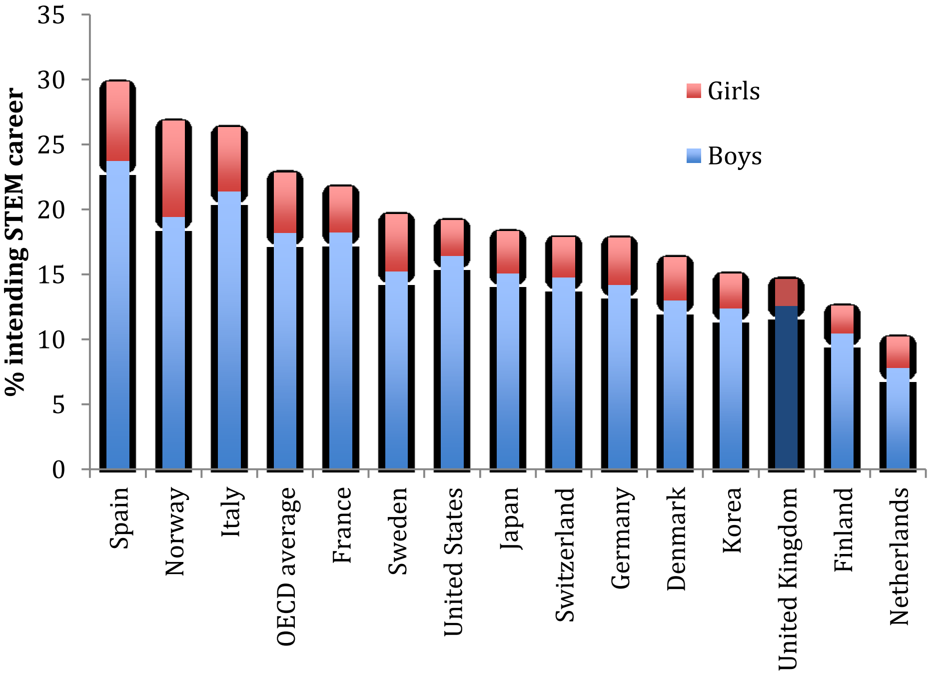
[6] Finland is notable for the low aspirations of their 15 year olds. However, there is large capacity in higher education to study engineering and the proportion of Finnish students who study this is more than double the UK proportion; and the proportion enrolled across STEM subjects is higher than the UK. The low level of wages for engineering graduates is thought to be a contribution to their high growth rate (see Honkapohja *et al* (2009)).

Figure 1 *STEM as % of total curriculum time: 12-14 yr olds*



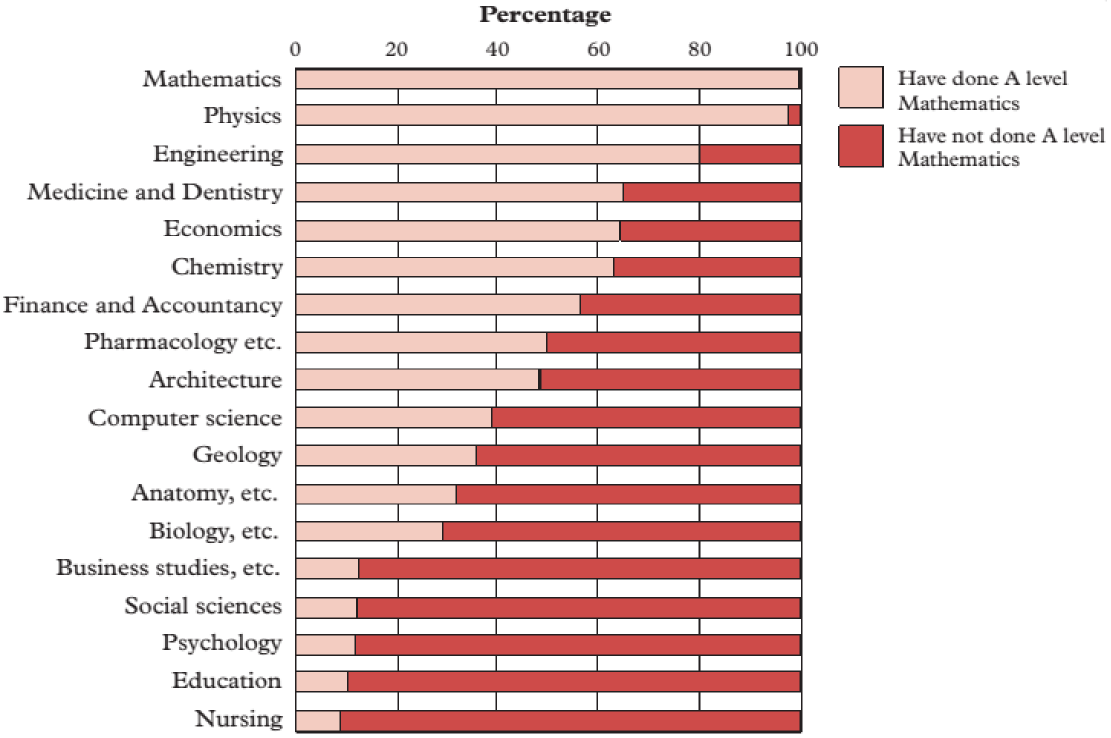
Source: OECD *Education at a Glance* 2012

Figure 2 *% intending STEM career: age 15*



Source: OECD *Education at a Glance* 2012

Figure 3 Mathematics A-level and Choice of Major



Source: House of Lords Report, 2012

3.1.4 Empirical evidence on choice of high school curriculum

There is relatively little empirical work on how high school students (that is aged 16-18 in the UK context) choose their curricula. In the UK there has been a weak trend towards encouraging greater breadth in senior high school. Course-taking overall is up, and in particular, course-taking in core academic subjects (mathematics, science, social science, and English) have all increased. Furthermore, the percentage of students taking more rigorous programmes of study has increased as well. The UK time series numbers of students taking various A-level subjects show a rising trend for mathematics over the last decade after consistently falling for the previous two.

In the US part of the trend is due to changes in state level graduation requirements in mathematics. To some degree, US state requirements reflect perceptions of what is required for the labour market and for post-secondary education. In the UK, subject pre-requisites for admission to university to study specific subjects exist. However, unlike the US there is no general expectation that applicants will have studied a greater quantity of courses than usual – there is no real UK equivalent to the US senior high school Advanced Placement (AP) courses that aim to prepare students better for college. For example, US undergraduates with a concentration in STEM will usually follow an AP calculus course in addition to the regular high school mathematics.

There does not appear to have been much quantitative research on high school curriculum choice. Zietz and Joshi (2005) use the US NLSY (1997) to estimate the determinants of choices and find that "academic aptitude, pre-high school academic performance, and lifetime consumption goals as driven by peer pressure and family background are by far the most important determinants of programme choice." Meer (2007), using the NELS88 data, finds that students choices between academic and vocational high school curricula are driven, in part, by comparative advantage – what students expect will be enjoyable and lucrative. There seems to be no studies that bear directly on the choice of STEM in particular at high school.

3.1.5 The effects of high school curriculum on educational attainment and wages

There is surprisingly little quantitative research about the causal effects of specific high school courses on educational attainment and labour market outcomes. Data availability is a problem. So far it has not been possible to link the requisite administrative datasets in the UK to illuminate this. However, data is not the only problem. Student course selection is not random given the available options. Furthermore, student curriculum choices are shaped by school requirements, tracking policy, and guidance, and these reflect to some extent the qualifications and interests of the student body and even the qualities of teachers in different subjects within the school. Even with excellent data, it will be difficult to identify the *causal* effects of educational attainment, the choice of high school A-level subjects, and then the choice of subject at university (one's major) on labour market success.

However, since there are so many possible choices open to students the prospect of being able to model the fine detail of the effect of taking one subject rather than another looks like a remote prospect. A notable study for the UK is Dolton and Vignoles (2002). They investigate the impact of different academic subjects in UK secondary schools on pupils' subsequent earnings, particularly the impact of studying advanced level mathematics. Their most notable finding is a very large return to having mathematics A Level, of the order of 10%, even after controlling for undergraduate and postgraduate degrees. This result seems to be robust even after controlling for the initial ability of these individuals and their subsequent educational attainment. The result is for students in the late 70's and early 80's but it seems like a remarkable result and it would be hard to argue that it has any less relevance now than it had then.

Altonji (1995) was probably the first comprehensive study of the effects of curriculum on post-secondary educational attainment and wages. He uses data from the US National Longitudinal Study of 1972 (NLS72), and divides courses into academic, vocational, and "other" courses rather than looking at specific subjects. He exploits the substantial amount of variation across US high schools in the extent of choice available to students as an "instrumental variable" for the actual choices that individuals make. That is, he assumes that the restrictions on subject choices that individuals find that they face when in high school does not affect their earnings *except* through its impact on the choices they actually make. Then comparing the outcomes (wages) for people with wide availability of choices and people with narrow choices allows one to estimate the causal effect of the choices that are observed on wages. Altonji's estimates indicate that the effects of additional courses in academic subjects are small. Even when controls for family background and ability are excluded, the combined effect of an extra year of science and mathematics is to raise later earnings by only 0.3 percent - far less than the estimated value of a year of high school in general. This figure falls to effectively zero when family background controls for the student and the school are added. So there is some evidence that even the upper bound of the effect of additional STEM at US high school is very low and could even be negative if one accounted for the opportunity cost of taking a STEM course rather than some other course.

Two studies take advantage of curriculum reforms that were driven by the US "A Nation at Risk" (Gardner, 1983) report. In the years following this influential report, a number of states established course requirements in core academic subjects or increased existing ones, and made successful completion in core subjects a condition for high school graduation. This encouraged greater effort in core subjects that was reflected in coursework completion and prompted schools to provide additional classes for those achieving below some level. This allowed states that adopted reforms at different times to be compared, and students achieving just below the threshold level with those just above to be compared. Cortes *et al* (2013) find that an extra high school mathematics course had large effects on test scores, high school graduation and HE participation. Goodman (2012) showed that the increases in core subject standards had an important effect on black male high school coursework completion and subsequent earnings – in the range 5 to 9%. The suggestion is that imposing minimum standards improves outcomes for weak students. These studies are identifying what is effectively the impact of being compelled to study mathematics for weak students. Altonji is identifying the effect of compulsory mathematics and science in his work – but for all students. The Altonji results suggests that the effects of forcing an average student to do maths and science at the expense of something else they would rather take is small, while the Goodman and Cortes *et al* results suggest that the effects of compelling more mathematics on weak students is important.

Ultimately, the most convincing study in this topic is that by Joensen and Skyt Nielsen (2009) who estimate the causal effect of studying advanced high school mathematics by exploiting an educational reform in Denmark. Until 1984, students could only take advanced mathematics in combination with advanced physics. This was changed in 1988 to also allow students to combine advanced mathematics with chemistry. This seemingly modest reform was piloted at some high schools during the years 1984 through 1987. They find that taking the advanced mathematics course in combination with the advanced chemistry course increases earnings by 20% relative to chemistry without mathematics. This study is a valuable contribution that illustrates the potential for research that exploits sharp curriculum reforms - and provides an extremely large estimated effect in this case.

The US research suggests that raising maths participation in high school through restricting choice has modest effects. While the UK and Danish research seem to point to large effects of high school mathematics on later earnings even controlling for overall educational attainment when this is driven by expanding choices.

3.2 Higher education and earnings

3.2.1 Background

In analysing the private returns to education the standard empirical approach is to explain the variation in earnings across individuals using regression methods, where the explanatory variables include years of schooling, labour market experience, and other characteristics. The evidence that earnings are positively associated with schooling is robust and uncontroversial; the obvious difficulty lies in giving this association a causal interpretation. The recent focus of the literature on education has been on using natural experiments, in the hope that these will allow stronger claims about causality to be made. Researchers look for situations in which the level of schooling varies across individuals for reasons that are likely to be independent of the unobserved characteristics of those individuals (ability, determination, and so on).

3.2.2 Empirical research

The empirical literature has been focused on overcoming the bias in regression studies that is associated with omitted "ability". The argument is that the coefficient on the education variable picks up the effect of omitted ability as well as education. Since the latter are positively correlated and since ability, controlling for education, is likely to raise wages, regression studies overestimate the causal effect of education. Most studies that address this issue rely on education reforms that raise the minimum level of schooling and are probably of limited relevance. Only Card (1993) provides estimates that bear on the effect of higher education on earnings. He exploits the changes in college attendance in the US associated with changes in college proximity that arose from the expansion of higher education provision in the 1960's. Much of this expansion was driven by opening new campuses rather than expanding existing ones. Card finds that the earnings effect induced by the greater college participation was much larger that the estimate that a simple regression based study showed - suggesting that ability bias was important. However, he did not decompose his analysis by college major.

3.2.3 Changes in returns over time

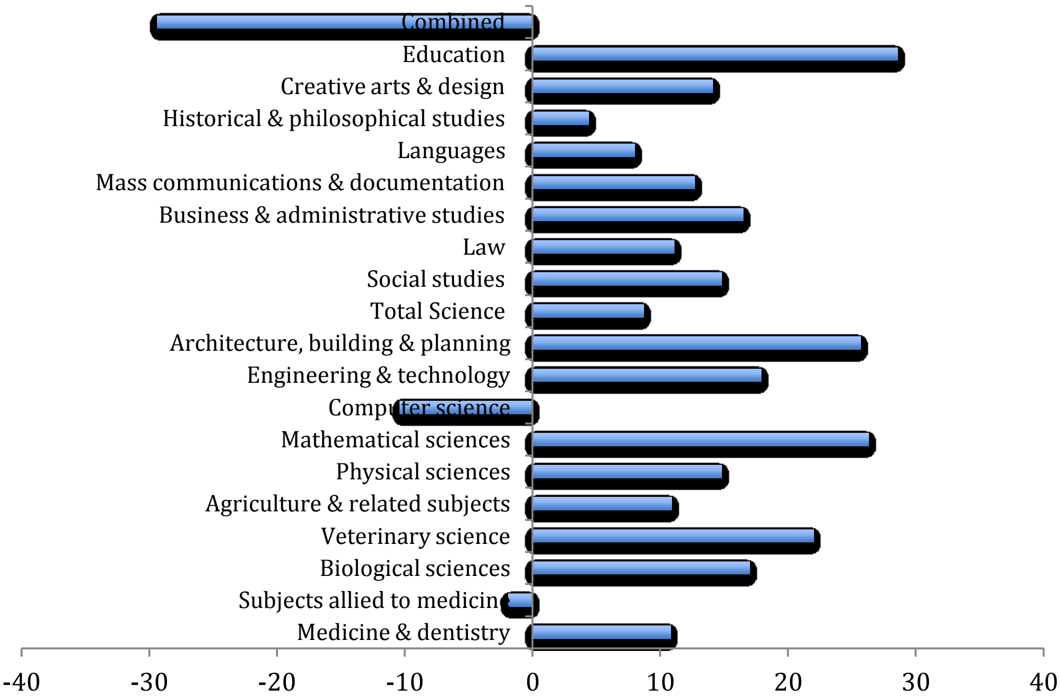
There is extensive evidence that the impact of education on real incomes is sensitive to the demand for and supply of skilled workers. Indeed, it is widely believed that in the race between technology and education it is education that is losing and the result is that we observe widening inequality in earnings between highly skilled labour and the rest. Although skill-biased technological change has generated rapid growth in the relative demand for more-educated workers for at least the past century, increases in the supply of skills, from rising educational attainment of the U.S. work force, more than kept pace for most of the twentieth century. Since 1980, however, a sharp decline in skill supply growth driven by a slowdown in the rise of educational attainment of successive U.S. born cohorts has been a major factor in the surge in educational wage differentials. Recent work has also argued that labour market "polarisation" set in during the late 1980s with employment shifting into high- *and* low-wage jobs at the expense of the middle. The polarization argument is consistent with the idea that blue collar manufacturing jobs have been exported to developing but low wage economies or have been automated, and repetitive white collar and clerical work has also been offshored and computerised. The manual service sector jobs in retailing and hospitality have been largely immune from this – leaving a labour market which has been "hollowed out".

There are many studies that show that the effect of higher education ("college" in US parlance) is large and has been getting larger over the last 40 years. This is true in the US and it is also true in the UK, and in many other developed countries. While there has been extensive research on education levels generally and the impact of college in particular, there has been less progress on identifying the causal effects of the curriculum content of this education. One of the major drivers of rising earnings inequality is said to be skill biased technological change. It seems plausible that this will widen the STEM vs. non STEM earnings premium - but we are not able to point to any studies that have investigated this.

3.2.4 Trends in college major

Altonji *et al.* (2013) show that, consistent with the US high school course-taking trends, the fraction of science majors has shown a slight rise in recent years. Taking a longer view, the fraction of education majors has decreased substantially over the past forty years, while the proportion of business and economics majors peaked about twenty-five years ago, following a period of rapid growth in the 1980s. Figure 4 shows the UK JACS3 level growth rates in acceptances for 2005-2010 (full-time). The average across all subjects was 11% so there has been considerable relative growth in STEM, especially mathematics, with the exception of computer science. This is encouraging and one might speculate that it arises because of the high levels of wages associated with STEM subjects.

Figure 4 Changes in UK major choice (% change between 2005 and 2010)



3.2.5 The role of expected earnings on major choice

Almost all of the existing literature is based on relating student responses to questions about their knowledge of the earnings distributions across subjects to the students own choices. There is a danger that the method simply picks up unobserved student factors – students who are well matched to a subject, perhaps because of family connections, think they will do well because of those connections rather than real comparative advantage. The only work that relies on observable data on relative earnings and subject choices is by Beffy *et al* (2012) who investigate subject choice in French universities and how that responds to cyclical variation in relative wages. They find very small elasticties – for example their model predicts that a 10% rise in STEM student earnings would result in only a ¼ percent rise in the number choosing STEM. Almost all of the variation in choice is driven by non-pecuniary factors – student preferences and abilities. However, the model is essentially short run in that it is based on responses to cyclical variation in wages, so it may underestimate responses to permanent changes in labour market relativities. They speculate that this may also be due to hyperbolic discounting – student choices are heavily influenced by the enjoyment of the course in the present, but the effect of future earnings are heavily discounted and have little effect. The suggestion here is that it is not information that matters but short termism by students.

3.2.6 Returns to college major: empirical evidence

Unlike the literature on the returns to high school curriculum, the literature on the returns to college curriculum is more substantial. There are a number of prominent US studies and a small number for the UK. We know of none elsewhere. Estimating the returns to college major is fraught by multiples of the confounding variable difficulties that plague estimations of the return to college on average.

Berger (1988) is one of the few US papers that attempts to address selection in the context of major choice. He models the five major categories of major and finds that students choose majors on the basis of the present value of expected lifetime earnings. To identify the model, he allows family background variables (father's occupation, parental education, race, etc) to affect the choice of major without affecting earnings and allows ability measures (IQ) and cohort to affect major choice only through the earnings equation. Both of these assumptions are questionable. Nonetheless, choosing a science degree was sensitive to relative wages.

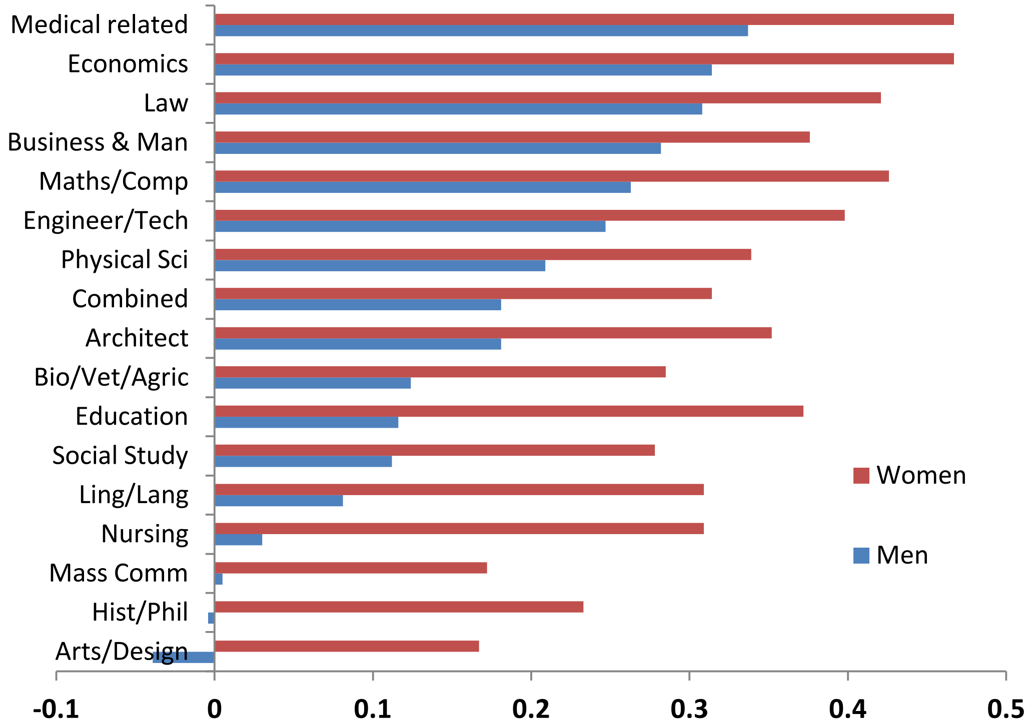
Altonji *et al* (2013) provide US evidence on the relative returns to a detailed breakdown of college major newly available in the US American Communities Survey dataset. Unfortunately, the data set lacks test scores and family background measures so the case for thinking of these as approximating causal effects is weak. They also find that differences across US majors are large. Consistent with results in the literature, the Altonji *et al* (2013) estimates show that engineers have the highest returns and education majors the lowest. In most fields the size of the premium over a general education degree is higher for *men*. For men (women), a shift from a college major that is one standard deviation below the mean to one that is one standard deviation above the mean is associated with an increase of 35% (30%) in earnings. How much of the differences in returns is due to differences in the market value of tasks that require the specific knowledge and skills that particular majors develop, and how much to prior skills is not known.

There has been speculation that the difference in returns across majors is due to difference in mathematics ability. Paglin and Rufolo (1990), for example, explain 82% of the variance across college majors in post university wages on the basis of pre-university GRE-mathematics scores. One might also be interested in the effects of college major on occupation, and in particular, the extent to which human capital is major-specific. Robst (2007) shows that students who are employed in a field unrelated to their field of study suffer a wage penalty, suggesting that this is at least partially the case; however, the wage penalty varies by field. The most specific fields, such as engineering, suffer harsher penalties than fields which develop more general skills, such as liberal arts. Of course, working in an unrelated field might also be due to lack of success in the field that one majored in.

The existing UK literature on the effect of subject of study is thin (see Conlon and Patrignani (2011), Sloane and O'Leary (2005), and Walker and Zhu (2011 and 2013)) but the studies that do exist tend to report large differentials by major of study. The results are in broad agreement with the US work – and suffer from the same reservations. Broadly speaking, differentials are higher for: science, technology, engineering and mathematics (the STEM subjects); medicine, dentistry and veterinarian studies and for law (although here the high proportion of individuals who are self employed make firm conclusions difficult); management and economics; compared to the Arts and Humanities. No UK studies, to our knowledge, make any attempt to deal with the complex selection issues associated with major choice. Nor do they allow for self-employment that is likely to be an important factor in some subjects that lead to the professions. Nor do they allow for the impact of taxation or tuition fees (but see Walker and Zhu, 2013). In addition, there are probably some non-pecuniary, as well as pecuniary, differentials and it is unclear that the labour market compensates for such non-pecuniary differentials by subject of study. In our view, while the existing results are interesting, we are a long way from being able to draw policy conclusions from them. It would be inappropriate, for example, to conclude that there was a shortage of one type of graduate relative to another.

Figure 5 below shows the estimated gross earnings per hour differentials based on the large UK LFS data (similar to the US ACS). Here the results are presented relative to students who had 2 A-levels but had not attended university. The variance across majors is not as large as in the US – the difference between STEM, on average, and Humanities, on average, is around 20%, while the average differential between UK graduates and those with 2+ A-levels but who did not attend university is around 30%. The UK estimates suggest that the returns are higher for women. However, women in the UK tend to be concentrated in low return subjects - although inspection of the cohort trends in the LFS suggests that this has been changing slowly over time.

Figure 5 Baseline UK LFS estimates by major



Note * Medical related excludes medical and dental graduates who exhibit a very high degree of self-employment for whom we do not have income data.

Walker and Zhu (2013) also consider the effect of college major on the probability of employment. On average we show that a first degree has a strong effect on employment. While graduate unemployment doubtless exists, it is smaller than unemployment amongst non-graduates. Nonetheless there are strong differences across majors that broadly reflect the estimated earnings differentials conditional on employment.

The expansion in HE in the UK in the 1960's and more recently in the early 1990's has not changed the balance across majors radically - although there has been a slow move towards a more even gender balance. There has been a sharp change in the gender mix of medical students in the last two decades and some change in within-STEM gender composition. However, Figures 6 and 7 shows that the UK still lags behind most OECD countries in women's aspirations to study a STEM subject and engage in a STEM career.

Finally, there is also a small literature on the impact of college quality (see Eide *et al* (1998) and Hoestra (2009) for the US, and Hussain *et al* (2009) for the UK). Hoestra (2009) is the most convincing study since it exploits a sharp discontinuity in admissions criteria to show that attending a "flagship" state university in the US increases earnings by about 20%. In the UK work by Hussain *et al* (2009) estimates that the effects of their proxy for HEI quality on earnings is statistically significant, but small compared to the overall return to higher education on average – they cite a one standard deviation in HEI quality results in a 6% earnings difference. However, this study uses the Destination of Leavers of Higher Education (DLHE) surveys of graduates early in their careers when there is considerable noise in earnings.

There is a worry that the omission of HEI type might bias the estimates of effects of subject - because higher quality HEIs are likely to have a higher proportion of students studying the traditional high return subjects such as law and STEM. In the UK Chevalier and Conlon (2003) consider the impact of attending a Russell Group institution and find small positive imprecise effects that were sensitive to the specification. This is surprising in the light of the attention given to this issue - indeed, much has been made of the differences in HEI choice of student from low income backgrounds. Walker and Zhu (2013) show similar weakly results of HEI type.

It would be useful in the UK to have a large panel dataset that was long enough to see how graduate careers progress and big enough to be able to disaggregate by major in detail. It would also be useful to know the high school curriculum followed and their attainment grades. This is possible in several Scandinavian countries where population registers can be merged to form such a population panel – although this particular exercise has yet to be done there. In the UK, merging information from school records (the National Pupil Database, NPD), university application (Universities and Colleges Admissions Service, UCAS), graduation (Higher Education Statistics Agency, HESA), and subsequent earnings (Longitudinal Labour Market Database, LLMDB) would allow this - although we understand that the legal permissions to do so have not yet been put in place.

While the growth in the demand for skilled labour is thought to have been driven by SBTC there is considerably less evidence on how the composition of the stock of human capital affects the pace of growth. Even though the world of work has rapidly become a much more complex place because of the fall in the price of computing power, there is little evidence that this has affected relative incomes *within* the stock of graduates. For example, one might have expected technological change to have increased the relative demand of science and technology, engineering and mathematics graduates.

Figure 6 Women graduates by STEM major: selected countries

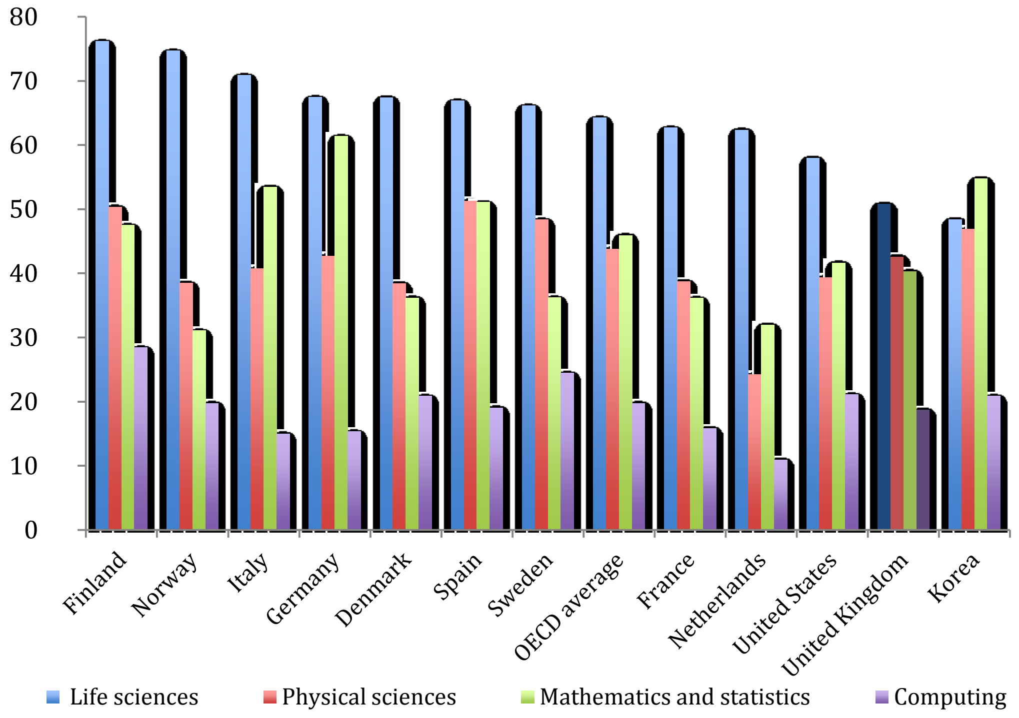
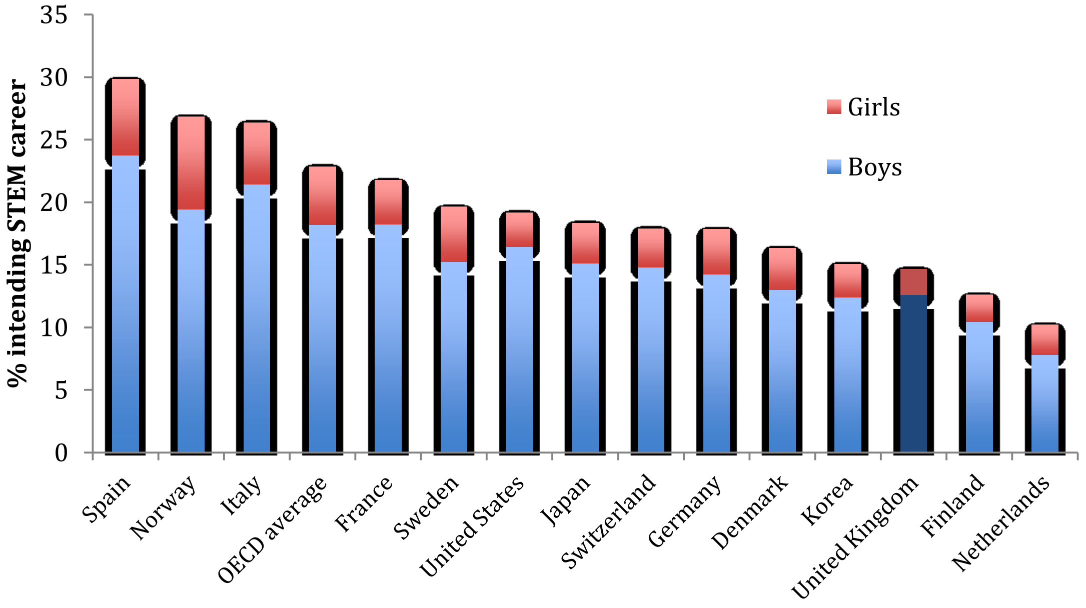


Figure 7 Girls intending to pursue a STEM career: selected countries



While there has been a huge literature that investigates educational attainment and "the return to education," with the more recent work focusing on heterogeneity in the return, there is much less work on why individuals choose different types of education and the consequences of those choices. In some ways this is surprising, because the question of what kind of education should be provided receives an enormous amount of attention in policy discussion and is a decision that every student must make, particularly at the post-secondary level. Periodically, there are calls for reform of the high school curriculum, often in response to concern about the readiness of students for the work force. An important US example is “A Nation at Risk” (Gardner (1983)). This report advocated a focus on the “new basics,” with an increase in the number of courses in key academic subjects such as mathematics and science. But despite the debate about what students should study, there is surprisingly little hard evidence about the labour market consequences of specific courses. At the college level, differences by field of study have received much less attention than has the average return to post-secondary education.

Education progression for students is complex and varied. It depends on aptitudes and skills developed during compulsory education, on preferences formed through parents and peers, and constraints associated with course availability and the varying quality of teachers across subjects. Even in early high school students face curricula choices that might have far-reaching consequences and they might do so in ignorance of these consequences. One reason that we have a compulsory level of education is to ensure that all students are prepared to be able to follow their preferences and abilities into good choices in post-compulsory education. Switching field of study in the face of new information about ability, preferences, and returns is costly. Indeed, knowledge accumulation is stochastic - students cannot simply decide that they are going to complete a programme of study, there is some risk of non-completion attached. They have to satisfy pre-requisites and progression rules. This makes for significant econometric difficulties that sequential choice in the presence of learning poses for estimating the causal effect of a field of study on wages.

More research could be done using variation across time and place in the demand for particular types of majors. A natural approach would be to use a regression discontinuity (RD) design in situations where certain majors have a test score cut-off or enrolment cap for entry. Some US universities use Grade Point Average (GPA) cut-offs as a way to ration access to some programmes. Of course, this is done for all courses and all institutions in the UK – but the course/institution specific tariff requirements may be relaxed if demand turns out to be lower than expected. However, modelling the setting of the tariff requirements, student responses to them, and the “clearing” system that matches frustrated applicants with under-recruiting courses would be difficult. The opportunity for using RD approaches to identification is greater in countries that admit students to particular programmes and particular colleges based only on published test scores requirements – Australia and Denmark spring to mind.

3.2.7 Postgraduate STEM

Over the past few decades, there has been a dramatic rise in postgraduate (PG) education in developed countries, including the UK and the US. However, the literature on postgraduate education remains thin, with most of the emphasis on its impact on increasing wage inequality. The study of postgraduate degree subject is difficult in both the UK and the US. Only the major of undergraduate degrees is known in the UK LFS and the US ACS.

Using a supply-demand framework, Lindley and Machin (2012) show that there have been trend increases over time in the relative demand for postgraduate vis-à-vis college only workers in the UK and the US, implying that postgraduates and college only workers are imperfect substitutes in production. Moreover, they also show that the relative demand shifts are significantly correlated with changes in industry computer usage and investment that favour postgraduates and the occupations in which they are employed relative to those of undergraduate only graduates.

Dolton *et al* (1990) is a notable paper for the UK. This uses a 1980 cohort of UK university graduates with earnings data observed just six years later. This so identifies the effect of HE qualifications including PG at a single, and rather early, point in the lifecycle and this is likely to be a poor guide to overall lifecycle effects.

Walker and Zhu (2011) estimate the effect of post-graduate education on earnings by broad group of majors using the UK LFS data. The return to PG training is significantly positive for all four groups of major for both men and women. The return, when averaged across the average duration of post-graduate training, is lower than for undergraduate training and the differences between the returns for STEM postgraduates and the other groups is never statistically significant. There is no compelling evidence of a high return for advanced STEM training in the UK data.

Lindley and Machin (2011) also use the LFS data but focus on the changes over time rather than differences by major. Their average (across time) results are close to the Walker and Zhu average (across major group) results. They estimate that the premium for a Masters (PhD) degree relative to a Bachelor degree rises from 8% (14%) in 1996 to 11% (24%) in 2009. These rises suggest that, while the expansion of undergraduate provision has moderated the earnings of undergraduates, the smaller expansion at the postgraduate level may play a role in the growing differentials between under and post graduate earnings. However, they do not decompose their changes over time into STEM vs other categories of HE.

3.3 The external effects of STEM and the case for subsidy

Much of what is claimed to be an external benefit would, if labour markets worked sufficiently well, be properly regarded as private benefits. For example, if there were a causal effect of expanding STEM provision, say in HE, on, say, innovation that benefitted their employer more generally then one might be tempted to include this as an external benefit. However, if there were such a link then we would expect an efficient labour market to provide levels of pay for STEM graduates to reflect this aspect of their productivity. For example, if there is a spillover from STEM graduates on non-STEM worker productivity within firms then we might expect STEM graduate pay to reflect this.

Similarly, defining non-economic benefits to include such things as the role of elementary financial literacy on financial decision-making (for example, on saving and pension provision), and even on risky behaviours such a crime, unprotected sex, obesity, and substance abuse is arguable. At least some of these effects benefit the individuals concerned. Even arguments that rely on inter-generational effects are suspect if it is the case that individuals are altruistic towards their children and are able to make appropriate investments on their behalf.

3.3.1 The external economic returns to acquiring STEM skills

The case for subsidizing HE investments ultimately rests on arguments that there is too little of it. That is, the market mechanism does not, for some reason, provide the right incentives for individuals to make the right amount and type of investment in human capital; or, if it does, then individuals are not, for some reason, able to respond to those incentives. The case for subsidizing human capital in general, or in some specific area, relies on a market failure argument.

The idea of human capital externalities is that social interactions on-the-job create learning opportunities that may generate productivity externalities across co-workers. However, empirical research on the existence of the spillover effects has been plagued by data availability at the individual level and the problems of uncovering causal effects from correlations.

The empirical literature on the social returns to higher education in general, and STEM majors in particular, can be usefully classified into two main strands, by the level of aggregation of the studies. The first strand focuses on local labour markets, usually cities (or metropolitan areas) and regions. The second takes advantage of firm-worker matched datasets to study educational spillovers at the plant level but there is not a single study that takes this approach that specifically addresses STEM.

The idea here is to estimate human capital earnings functions in the normal way, but include the average level of schooling in each individual's city or region in the function. If there are significant externalities to human capital, individuals should earn more when they work in those cities with a higher average level of schooling. The exercise will miss externalities that work at the national level, perhaps through social structures or institutions, but it remains of considerable interest.

Rauch (1993) pioneered empirical research on productivity gains associated with the geographic concentration of human capital. Using the Microdata Sample of the 1980 Census of the Population of the US collected on a Standard Metropolitan Statistical Area (SMSA) basis, he presented the first evidence on the magnitude of the social returns, controlling for SMSA characteristics. Several studies based on this idea have been carried out for the US. The initial results of Rauch (1993) appeared promising. Consider two otherwise similar individuals living in two different cities, the second city with a population that has an extra year of average schooling. His estimates suggested that an individual living in the second city could expect to gain a wage premium of around 3 per cent: an effect large enough to be worthy of further investigation.

To account for the unobservable characteristics of individuals and cities which might raise wages and be correlated with the share of college educated workers in the workforce, Moretti (2004) used the National Longitudinal Study of Youths (NLSY), a longitudinal dataset of 12,000 individuals, to track the changes in the salary of a given individual over time as the share of college graduates in her city changes. He exploits the fact that two variables, earlier city demographic structure and the presence of a land-grant college[7], affect the share but do not directly affect wages. He finds that a one percentage point increase in the supply of college graduates in a city raises high school dropouts' wages by 1.9%, high school graduates' wages by 1.6%, and college graduates' wages by 0.4%.

Acemoglu and Angrist (1999), Rudd (2000) and Ciccone and Peri (2006) all extend Rauch's approach to a panel of U.S. states and account for state effects as well as for the endogeneity of average and individual schooling. However, they all fail to find any significant productivity effect of increased average schooling. Iranzo and Peri

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[7] A land-grant college is an institution of higher education in the United States designated by a state to receive the benefits of the Morrill Acts of 1862 and 1890, with an aim to promote the teaching of practical agriculture, science, engineering, and military science.

(2009) attempt to reconcile the mixed evidence by distinguishing between highly educated workers (say college graduates) and less educated worked (say high school graduates). They exploit the variation in college share arising from US states varying their compulsory attendance and child labour laws, at different times, as well as variation in the push-driven immigration of highly educated workers, and by differences in the location of land-grant colleges. They find that an increase in college education, but not an increase in high school education, had significant positive productivity externalities.

It appears that Peri *et al*. (2013) and Peri and Shih (2013) are the only studies that explicitly look at the effect of STEM workers on employment and wages of other workers in the same local labour market. Both papers exploit the exogenous variation in the stock of foreign-born STEM workers induced by immigration policies, in the US and Canada respectively. Peri *et al*. (2013) find that a one percentage point increase in the foreign-STEM share of a city's total employment in the US increases wages for both STEM and non-STEM native graduates by 4-6 percentage points with a small beneficial effect on their employment. On the other hand, there was no significant wage or employment effect for non-graduates. Peri and Shih (2013) show, for Canada, that a one percentage point increase in the foreign-STEM share of an area's total employment increases wages for native graduates by 5 percentage points with a smaller positive effect on their employment. They also conclude that STEM workers contributed significantly to productivity growth.

3.3.2 The non-economic returns to acquiring STEM skills

Over the past decade, a literature on the non-economic returns to human capital has begun to emerge. Educational provision may affect public health, crime, the environment, parenting, and political and community participation. Some of these effects are discussed in more detail in OECD (1998, Chapter 4), Behrman and Stacey (1997) and Haveman and Wolfe (2001). A number of specific studies are worth noting. Milligan *et al* (2004) explore the compulsory schooling laws in the US and the UK to study the causal effect of education on the likelihood of political participation. They find that more education increases several measures of political interest and involvement in both countries. Moreover, they find a strong and robust relationship between education and voting for the US, but not for the UK. The very recent work by Cole *et al*. (2012) provides the first precise estimates of the causal effects of education on financial behavior in the US. They exploit the effect of changes in state compulsory education laws on education to infer that one more year of schooling increases the incidence of reporting positive investment income by 7.5 percentage points. They also find that cohorts induced to have more years of schooling have higher credit scores on average and are significantly less likely to be delinquent, declare bankruptcy or experience a foreclosure during the financial crisis. There is a strong presumption that education improved ones financial literacy and considerations of credit market imperfections suggests that this might be a useful social benefit. It seems likely that mathematics would play a more important role than education in general in this but there is no direct evidence to show this.

3.4 The long run effects on the living standards of future generations

A parallel literature considers the impact of education on the productivity, not of contemporaneous workers, but of workers in the future. – i.e. on growth.

3.4.1 Background

Endogenous growth models that incorporate an analysis of research and development, notably Romer (1989), yield the result that the steady-state *growth rate* partly depends on the *level* of human capital. The underlying assumption is that human capital is a key input into the production of new ideas. This opens up the possibility that even a one-off increase in the stock of human capital will raise the growth rate indefinitely. In most endogenous growth models based on research and development, the stock of human capital is taken to be exogenously determined. Acemoglu (1997) and Redding (1996) and subsequent papers have relaxed this assumption, and considered what happens when individuals can choose to make investments in education or training, while firms make investments in R&D. In these models multiple equilibria are possible since the incentives of workers to invest in human capital and those of firms to invest in R&D are interdependent. This provides a way of formalising earlier ideas about the possible existence of a "low-skill, low-quality trap" in which low skill levels and slow rates of innovation reflect a co-ordination failure (Finegold and Soskice, 1988). The models suggest that, at the aggregate level, greater investment in education or training might raise expenditure on R&D, *and* this induces further education. While the curriculum content of education has not been explicitly incorporated into such models it seems likely that the theory applies more strongly for STEM education that complements innovative activity. Romer (2000) has pointed out that models of growth driven by R&D should potentially inform education policy. In particular, policy that incentivizes innovative activity, such as R&D tax credits, may be ineffective unless they encourage a greater number of scientists and engineers to work towards developing new ideas.

3.4.2 Evidence from growth regressions

Starting with Pritchett (1996), researchers have noted the implications of traditional earnings functions for analyses at the cross-country level. If an individual's education contributes directly to their productivity, in the manner envisaged by labour economists, we should expect to observe a correlation between the change in output per worker and the change in average educational attainment, at least after controlling for other variables. Furthermore, it should be possible to detect this effect regardless of whether or not the initial level of educational attainment determines growth. This argument has shifted the focus of research towards regressions that relate growth to the change in educational attainment, rather than its level. Several well-known studies have found the correlation to be surprisingly weak; Benhabib and Spiegel (1994) and Pritchett (1996) both come to this conclusion for a large sample of countries. Nevertheless, Benhabib and Spiegel do find a statistically significant correlation between the level of educational attainment and growth for the wealthiest third of the sample (their Table 5, model 2).

Lindahl and Krueger (2001) have argued convincingly that an important problem is likely to be measurement error. The difficulty is that a specification based on an aggregate production function (as in Benhabib and Spiegel) typically seeks to explain growth using the *change* in educational attainment, but first differencing the education variable in this way will usually exacerbate the effect of any measurement errors in the data. Measurement error in an explanatory variable will attenuate (bias towards zero) the true effect of that variable. Drawing on national sources, and more recent figures compiled by the OECD, de la Fuente and Domenech (2006) compile a new and more reliable data set for years of schooling in OECD countries. In their empirical work, they find that changes in output and educational attainment are positively correlated, even in panel estimates that include country and time fixed effects. This supports the idea that, where previous researchers have failed to detect an effect, this may be due to measurement error.

One of the main reasons why the social rate of return is believed to be higher is that we think that knowledge "spills over" from the inventing firm to other firms. Once invented, an idea can be imitated by others (it is "non-rival" and only partially "excludable"), although patent protection and delays in the dissemination of new ideas does enable the innovator to appropriate some of the rents from a new idea.

Conventional wisdom holds that market mechanism is unlikely to provide sufficient R&D. There are two main reasons for this. First, R&D produces innovations that may have a public good element to them - so firms are unwilling to invest in innovations where they cannot appropriate the benefit for themselves. Patent protection probably goes some way towards overcoming this. Secondly, R&D is risky and financial markets may fail to provide sufficient funding – if firms face rationing in the external credit market then their innovative activities may be limited by their profitability. For these reasons the social rate of return to R&D will exceed the private rate of return and, therefore, R&D should be subsidized. Empirical research suggests that this issue is statistically and economically significant. The US and UK governments have directly funded a large fraction of total R&D spending through universities and defence. However, there is a serious problem with such government efforts to increase inventive and innovative activity - the majority of R&D spending is actually just salary payments for R&D workers. If their labour supply is inelastic then when the government funds R&D, a significant fraction of the increased spending goes directly into higher wages. Goolsbee (1998), using US Current Population Survey (CPS) data on the wages of scientific personnel, shows that government R&D spending raises wages significantly, particularly for scientists related to defense such as physicists and aeronautical engineers. Because of the higher wages, conventional estimates of the effectiveness of R&D policy may be considerably overestimated. The results also imply that by forcing up the wages of scientists and engineers, even for firms not receiving federal support, government R&D funding directly crowds out private inventive activity. A similar argument could be made in the case of indirect interventions – for example through the provision of tax credits for R&D spending in the private sector. There is a strong implication that policies to expand R&D, and so promote growth, need to be complemented by expanding the supply of R&D workers.

While recent research tends to find a positive effect of schooling quantity on economic growth, it seems beyond the scope of current data to draw strong conclusions about the relative importance of different mechanisms by which schooling quantity may affect economic growth.

To date this argument has not been extended to argue that the composition between STEM and non-STEM of HE is important.

4. Discussion, conclusions and recommendations

4.1 Discussion

The question of the role of STEM education is a broad one and simple cross tabulations or correlations have the potential to mislead because they may be confounded by omitted variables. We are fortunate in the UK in having some large and detailed datasets to help us. However, when addressing the impact of STEM, in particular, we can be slicing the data thinly and run the risk of finding too little power in the data to provide sufficiently precise estimates. While our very detailed cohort data (NCDS and BCS) gets more useful as its subjects age, it also gets less relevant to current labour market issues. And while LFS data is up to date it is less detailed than the cohort studies - for example, that there is no information about the subjects of qualifications below degree level is an important shortcoming: but one that could be addressed through merging information from school records of individuals (at least in England) through to higher education, including postgraduate level, and into the labour market. Eventually this would become an invaluable resource for informing policy.

An important shortcoming of cohort studies is that it is difficult to use them to exploit natural experiments and reforms. By definition a cohort study just analyses a particular cohort who will all share the same institutional, legal, and policy environment. Thus, it is difficult to apply natural experimental methods, which rely on reforms affecting some people but not others. Policy evaluation in cohort studies is limited to the use of their rich covariates and matching methods which both, inevitably, ignore unobserved cofounders. The US, in contrast, is rich in potential natural experiments because of state differences in policy and in policy changes. While the UK LFS is large and similar to the US CPS data, there are fewer convincing natural experiments to exploit.

Inevitably, policy will have to rely on complementary evidence from outside the UK.

4.2 Conclusions

Despite the difficult questions that the topic has raised we have a reasonable amount of evidence that points to STEM education playing an important role in the economy. There is a large body of evidence that points to rising (or at least not falling) returns to skills in general and HE qualifications in particular. The balance of opinion is that these returns originate in the effects of the acquisition of those skills on productivity, not on pre-existing ability. These returns are large and beg the question of why such large returns persist. On the face of it, we would expect such large returns to attract even higher rates of HE participation and that would then reduce returns. The fact that the expansions in HE that have occurred in many countries does not seem to have significantly reduced returns supports the idea that the supply side is losing the race with demand which is driven by technological change.

If it is technology that is driving the demand side of the market for skills, as seems to be the case, then we might expect the returns to the most advanced skills to be particularly sensitive. This, we might expect the returns to postgraduate degrees to be driving the return to HE in general through a rising option value of a postgraduate training. Here, a credit market failure might play a role – while we have a sophisticated loan system in the UK and Australia and a somewhat less sophisticated one in the USA to cover undergraduate fees[8] there is no such organized programme for delaying the up front fees associated with postgraduate education. Even in the case of short postgraduate vocational courses such as one-year taught masters degrees there is a case for thinking that the large levels of fees common in some subjects is a real deterrent. The low levels of representation of UK students in postgraduate training despite high and apparently rising returns would suggest a credit market difficulty.

Similarly there may be grounds for thinking that skill biased technical change may impact STEM skills in particular. At the level of basic numeracy there is compelling evidence that mathematical skills, in particular, has a significant causal effect on earnings even into middle age and even if one controls for overall educational attainment. These returns to these skills again seem too large, given the relatively modest costs of acquiring them. Although it is beyond the scope of this review, the culprit here is likely to be less effective teaching in mathematics than in other subjects which raises the costs for students. The impact of IT literacy has been addressed in a small literature. Here the conclusions seem less clearcut. The seminal US work suggested large returns but more recent careful work, including for the UK, suggests that once one controls more effectively for the unobservable skills of the computer literate the returns seem more modest.

The role of the curriculum choice is the most difficult question because the choices that students make may reflect their unobservable skills and failure to account for these might mislead researchers in concluding that the choice of subjects matter. What is required is study this question using a curriculum reform. The most convincing example available, where one of the restrictions on choosing advanced mathematics in Danish high school was lifted, suggested large causal effects of studying mathematics at high school for those who were induced to change their choices once the restriction was lifted.

4.3 Recommendations

Even prior to the financial crisis there were signs that the long run rate of productivity growth was waning. It seems likely that underlying growth will be lower than it has been over the last three decades. This raises the question of what determines growth and what policy actions need to be taken to promote higher levels of growth. The financial crisis has made this even more pressing since it is clear that reducing debt levels will be substantially less painful if the economy is growing than if it is not. This, raising the level of growth has acquired a new urgency.

A considerable amount of evidence has highlighted the importance of education for growth. Not only is there a sizeable evidence base that increasing average education levels raises average per capita living standards, there is also increasing evidence that raising average education raises the *growth rate* in real incomes, not just the level of real incomes. Precisely what the mechanism is that is responsible for this is unclear; but R&D is thought to also play an important role in both product and process innovation that leads to new products and cheaper ways of producing existing products. What is clear is that the vast majority of R&D expenditure goes on the earnings of scientific personnel. Growth policies that promote R&D will inevitably

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[8] Of course, fees are quite modest in most other countries so the issue of credit market efficiency is less important.

lead to a rise in the demand for scientific personnel so unless supply keeps pace R&D policies will be thwarted by the labour market. Such polices will simply serve to drive up the wages of such personnel.

Whether one can generalize from this finding that advanced mathematics at high school applies more broadly than to those who were on the margin of deciding to study mathematics is impossible to know. It is certainly true that England and Wales, and Scotland to a lesser extent, gives young students an early exit option from developing mathematical skills beyond the most basic level of GCSE. It is usual for some further mathematical training to be compulsory at the senior high school level. It is difficult to resist the conclusion that further mathematical development, or at least an obligation to maintain one's existing skills, should be mandatory from 16 to 18; but whether this should be compulsory A-level mathematics is not known. Although mathematics A-level is growing in popularity it has not yet grown much beyond the level in 2001 when the AS-level mathematics curriculum was widely perceived as too tough resulting in many students dropping this subject after just one year. STEM HE is built on mathematical skills acquired at an earlier point in the education process. So constraints at a low level will impact the domestic supply of high level STEM skills.

In the absence of sufficient domestic supply an alternative is higher levels of immigration. There is recent compelling US evidence that relaxing the visa restrictions on the immigration of highly skilled labour improves the earnings of native skilled workers. Similar research on how skilled immigrants in Canada disperse and the implications of this pattern on local labour markets suggests similar forces at work. China has dramatically increased the supply of graduates over the last decade. While much of this may be low quality there is evidence that the best Chinese institutions are becoming competitive with the best western institutions. Tapping into this potential supply could be an important contribution to receiving domestic supply shortages. The ubiquity of the English language makes this source, and others, more readily available than they are to non Anglo-Saxon countries.

5 Lessons for the Future

The demand for and, especially, the supply of skills is documented in Goldin and Katz (2008). They clearly demonstrate that US supply has not kept up with demand over the last four decades. The consequences has been rising inequality reflecting the rising returns to skills. Similar evidence has been found for many developed countries.

5.1 Trends on Domestic Demand

Quantitative research comes from the Institute for Employment Research as is based on input-output models of the economy and projections of demand by SIC, that then gets translated through the model into demand for specific types of labour. The modeling is based on assumption derived from projections of current trends. Thus, they embody the presumption that the demand for skilled workers will continue to grow and, in general, they find that STEM subjects will therefore experience faster growth in demand than others. Increasingly this work recognizes the supra-national nature of the market for advanced skills. For example, Wilson and Kreichel (2010) considers demand and supply across the EU up to 2020. They are also optimistic about supply pointing to large rises in HE participation rates across most EU countries over the previous two decades. They combine a macro model with many sectors with a general equilibrium model that imposes constraints across sectors to extrapolate that the main areas of employment growth will be in business and non-marketed services such as education and healthcare, distribution and transport, and in energy, rather than manufacturing and production sectors. The hollowing-out phenomenon that has been a feature of recent literature in labour economics is not featured.

Inevitably, the modeling ignores long term processes generated by technological change so is not going to capture the effect of new products that has had important implications over the last twenty years.

5.2 Trends in Domestic Supply

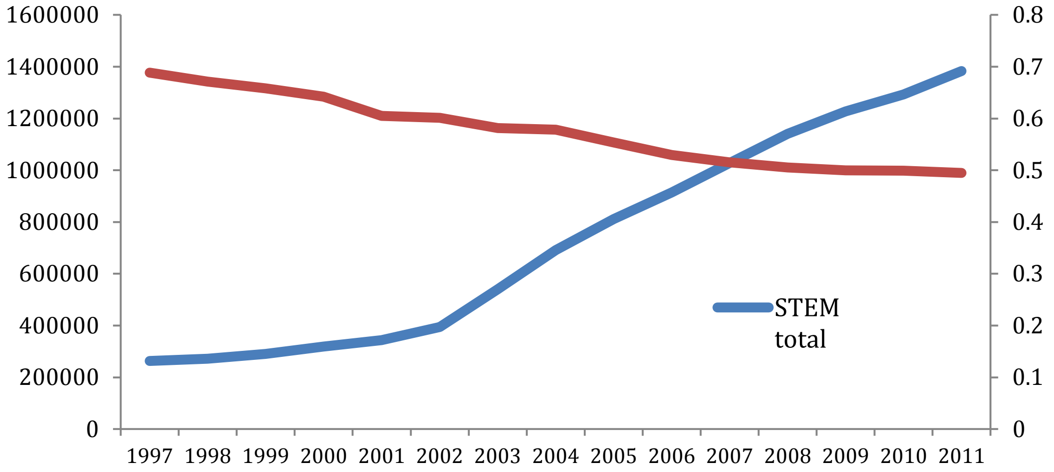
What the future will look like is less clear. In the UK the dramatic rise in the supply of graduates in the early 90's seems not to have had an effect on graduate earnings. It could be that the demand for experienced graduates has risen at the same time as the supply of inexperienced ones has risen. The size of young cohorts has been falling now for more than a decade so the supply of all young workers will fall for some time to come. This is not a demographic timebomb - unless the labour market fails to respond. We can expect to see a response in the form of rising female participation, rising participation rates for older workers, and it seems likely that there will also be a increased flow of skilled workers from southern Europe which has been badly affected by the financial crisis and the following recession. Whether further action is required to relax labour market inflexibilities is an open question. Two remedies offer themselves. First, the domestic supply of highly skilled workers could be stimulated through extending the credit provided by the undergraduate loan programme at least to those on taught masters students – subsidies to PhD students already exist. Secondly, visa restrictions could be relaxed to facilitate non-EU postgraduates to remain and work and to allow non EU students from further afield to enter the UK labour market more easily.

A variety of mechanical exercises have been conducted that attempt to relate observed wage differentials in the market to assumptions about supply to demonstrate what the demand elasticity of graduates looks like. While this may help us better understand the relationship between different types of labour it does not help us understand future demand in the absence of further assumptions about supply.

DIUS (2009) is optimistic about supply. It points to the higher proportion of STEM graduates per 100 working age population in the UK than Germany and many other comparable countries. The STEM proportion rose by 41% from 2002 to 2008. Others draw attention to the redistribution within STEM – away from traditional subjects towards sports science, forensic science, and psychology. The large proportion of STEM trained graduates working in non-STEM occupations adds to the impression that there is excess supply of STEM in the market. However, it is difficult to square this with the higher earnings for STEM graduates than non-STEM reported in most studies. Nor is it easy to reconcile with *ad hoc* employer surveys (for example, UK Commission for Employment and Skills, 2011) that, although piecemeal, generally point to STEM employers finding it difficult to hire STEM graduates of the appropriate quality. Shortages seem most likely reported in IT, engineering and biosciences and employers tend to complain of lack of practical experience by graduates.

Finally, foreign supply is likely to be buoyant. The HE sector in China has expanded rapidly in quantity and even though the variation in quality is still large the best of this sector will make a large difference to world supply of high quality graduates. Figure 8 shows the recent history of the supply of STEM graduates in China – even though the STEM share of graduates has fallen from 70% to 50% over just 14 years, the overall growth has been so dramatic that the annual STEM supply has risen from 200,000 to 1,400,000.

Figure 8 STEM supply in China



5.3 *Consequences*

Since the projections for both demand and supply are mostly driven by assumptions based on the past the consequences seem to imply that inequality will continue to rise, although probably more slowly because of the recent expansions in supply and the Great Recession. The market is international and while some R&D is clustered, some is footloose. The growing supply of STEM graduates in the Far East is likely to both pull electronics and related R&D towards it and be a source of graduates for the rest of the world. It seems likely that the rapidly growing capacity of the Chinese HE sector will dwarf variations elsewhere in the world.

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