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THE FUSION EFFECT

THE ECONOMIC RETURNS TO COMBINING ARTS AND SCIENCE SKILLS

A report for Nesta

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THE ECONOMIC RETURNS TO COMBINING ARTS AND SCIENCE SKILLS[1]

CONTENTS

SUMMARY

This research explores the fusion of arts and science skills in UK companies and the impact of this combination on performance. Using official UK data on innovation and firm capability, we analyse the finances of firms that use arts and science skills. We find compelling evidence to suggest that firms combining these skills are more likely to grow in the future, are more productive, and are more likely to produce radical innovations. Our findings support the hypothesis that the impact of arts skills in the UK economy extends beyond the creative industries.

KEY FINDINGS

- This report explores the performance of businesses with fused skills - those companies that fuse science and arts skills:
  - We estimate that these organisations employed over 3.5 million people and generated £500 billion turnover in 2011.
  - Although STEAM firms only make up 11 per cent of the population of non-micro firms, we estimate that they generate 22 per cent of employment and 22 per cent of turnover.

- While fused firms are widely perceived to be present in 'high-tech' and creative industries, we find them to be common in 'low-tech' and 'mid-tech' industries too.

- We find that firms combining arts and science skills, other things being equal, outperform those firms that utilise only arts skills or science skills:
  - They show 6 per cent higher employment growth and 8 per cent higher sales growth than other firms.
  - They are 3 per cent more likely to bring radical innovations to market.
  - They are 10 per cent more productive than the average firm, though they are somewhat less productive than science skills-only firms.
  - These positive effects hold across the entire economy, and are particularly strong for smaller firms.

- There is evidence that the broader the set of skills a firm uses, the higher its level of innovative performance and future growth.

1. INTRODUCTION

The ability of UK firms to access skills for growth has long been a national policy priority. Skills is one of the five cross-cutting themes of the 2014 UK industrial strategy,[2] and consequently much policy effort has been dedicated to strengthening the UK skills base. While the importance of skills is widely studied in terms of the relationship between human capital, skills and performance, there is rather less work considering the combinations of skills used by firms and their implications for firm performance. Our research aims to address this by considering the relationship between science and arts skills and firm performance.

One important and commonly discussed aspect of the UK's skills base is science, technology, engineering and mathematics (STEM) skills. STEM subjects are widely identified as key to UK national competitiveness, and consequently considerable investments have been made in promoting these topics at primary and secondary level and trying to ensure the financial feasibility of STEM teaching at the tertiary level.[3] Consistent with this, recent research by one of the authors[4] has also suggested that companies investing in STEM graduates outperform their rivals in terms of sales and employment growth and innovation.

Concurrent to this increased interest in STEM skills has been a challenging policy environment for arts education. On the one hand, arts graduates are popularly caricatured as doomed to poor earnings and underemployment.[5] On the other hand, the importance of creative skills, of which arts skills are one (but not the only) component, have been widely recognised. The 'creative economy', reflecting creative industries and those employed in creative occupations outside creative industries, has been widely hailed as a driver of jobs and economic growth. According to the latest official statistics,[6] the creative economy employed 2.8 million people in 2014, including 1.8 million in creative industries and 0.9 million creative professionals working in other sectors. This was up from 2010, when the creative economy consisted of 2.2 million people, including 1.2 million in creative industries and 0.9 million in other sectors. Further, the GVA generated by the creative economy was £133 billion in 2014, up 25 per cent from 2011.

At the same time, there has been growing interest in power of interdisciplinary work as a driver for creativity. Research in a number of fields has highlighted the benefits of different disciplinary, intellectual and personal backgrounds within groups on creativity at the personal, group and organisation level.[7] This literature suggests that working with people from different backgrounds provides a range of distinct perspectives that broadens search, provides better identification of opportunities and gives unique ways of taking advantage of these opportunities.

In this paper, we explore the performance implications of the combination of STEM and arts skills. The growth of investment in STEM and increased awareness of the creative economy have generally been understood as separate phenomena. However, recently there has been an increasing level of research and policy interest in the complementary effects of STEM and arts skills. For instance, the two AHRC-funded Brighton Fuse projects[8] identified possible dividends to bringing together creative and technical skills in one organisation, or even in individual self-employed workers. At the same time, Nesta, the Creative Industries Federation, the Cultural Learning Alliance, and others have joined to promote the integration of STEM and arts skills under a common STEAM (Science Technology Engineering Arts and Maths) framework.[9]

This research aims to understand and further elucidate the complementarities that exist between arts skills and STEM skills. The purpose of our research is to measure the impact of these combined skills on firm growth and innovation performance throughout the economy. In doing this, we expand on previous findings from the Brighton Fuse project, extending and further exploring these findings using representative, official data covering a representative sample of UK firms with more than ten employees.[10] Our main research question therefore asks whether the combination of arts and science skills produces performance dividends in terms of growth and innovation. In doing so our aim is to explicitly identify the contribution of 'fused' firms to the economy and to generate evidence on their economic performance. While previous studies have highlighted effects at the cluster level, ours is the first to generate evidence of an arts and science 'fusion' effect at the national level.

The report begins with an introduction, followed by a discussion of data and method in Section 2. We present our findings in Section 3, discuss these findings in Section 4, and conclude with policy discussion in Section 5. Main results then follow, and an appendix with results of further robustness checks is included.

2. DATA

The data we use in our analysis come from two official UK datasets: the UK Innovation Survey (UKIS) and the Business Structure Database (BSD). The UKIS is a biennial survey that is run by the UK Department of Business, Innovation and Skills as part of the Community Innovation Survey, which surveys innovative and non-innovative firms across Europe. The UKIS covers a weighted sample of firms with more than ten employees across the economy, with greater emphasis on firms in more technology-intensive sectors. The survey asks respondents about a broad range of their activities, including innovation, marketing, collaboration, sourcing of knowledge, intellectual property and skills.[11] Each wave of the UKIS is structured as a cross-section with a 'mini-panel' incorporated in it allowing for the observation of a smaller panel of firms across multiple waves. For our analysis we use the 2010 wave of the UKIS, which surveyed approximately 15,000 firms about their innovation activities from 2008 to 2010.[12] In addition, the 2010 wave was the first wave of the UKIS to ask each firm whether it had, during the period from 2008 to 2010, accessed any of a number of arts and STEM skills. The arts skills surveyed included design, graphics and multimedia (described as 'audio, graphics, text, still pictures, animation, video etc.'), while the STEM skills were software design, engineering, or maths. Importantly, the question was worded in a way to reflect skills used, whether involving staff or external contractors. In this sense therefore the focus of the question is more about the use of capabilities than the specific employment of staff with these skills. Our focus therefore is on the performance implications of the use of arts and science skills, and specifically their combination.

One major drawback of using UKIS data is that data on financial performance (i.e. turnover and employment) is self-reported and partially incomplete. In particular, the nature of the survey's 2008-2010 timeframe means that longer-term or forward-looking studies of growth (outside the UKIS mini-panel, which is limited as the key questions investigated in this paper, were only introduced in 2011) are therefore impossible without other data sources. In order to extend this cross-sectional data, we therefore link the UKIS cross-section to the panel of the UK Business Structure Database (BSD).[13] The BSD is a comprehensive database of all firms registered in the UK who pay National Insurance or VAT. The dataset includes employment figures derived from National Insurance records and turnover derived from VAT records. These are taken from the Interdepartmental Business Register (IDBR), a 'live' database of current records for these companies. The BSD is generated by taking a 'snapshot' of the IDBR at a certain point in time annually.[14] In the case of the data used here we were able to match UKIS data to the BSD, giving us more comprehensive records for firm performance during the period of observation (i.e. 2008-2010) and after (2010-2012). While the match is not complete,[15] our estimates comparing CIS and BSD data available show similar results. We therefore use the BSD performance figures as they allow us to use the same data to track performance throughout and after the observed period.

While our main analysis consists of the entirety of the population of firms captured within the UKIS, we also consider three subsets of the population of firms as well: creative industries, knowledge intensive business services (KIBS) and high-tech firms. To define creative industries we use the now-standard DCMS definition.[16] This includes the SIC codes for the advertising, design, architecture, TV and radio, publishing, crafts, museums and software sub-sectors. To define KIBS we use the OECD definition.[17] Because there is some overlap between creative industries and KIBS firms (particularly with regard to software), we exclude overlapping firms from the KIBS definition. To define high-tech we use the definition of high-tech firms from Nesta's 2015 report on the geography of the creative and high-tech economies,[18] which captures a broader range of high-tech activities than the OECD definition.[19]

2.1 VARIABLES

As discussed above, the key basis for our analysis comes from a set of questions introduced in the 2011 UKIS, which relate to skills accessed by the companies in question, asking if the firms used arts skills, including design, multimedia, and graphic arts, or science skills including software development/computer database skills, engineering, and mathematics. These yes/no questions were used to construct our key variables, for which we used two approaches. Firstly, any firm that reported using any of the design, multimedia or graphic arts skills was classed as using 'arts' skills, and any firm that reported use of software, engineering or maths was classified as using 'science' skills. Any firm using any science or arts skills was classed as having both (and was then excluded from the other two categories). This allowed us to create binary variables that are positive if a firm uses arts, science or arts and science skills. An alternate approach was also used as a robustness check, which involves coding these as part of a single categorical variable. We created a categorical variable that was coded as equalling zero if neither skill was used, one if arts skills were used, two if science skills only were used, and three if both arts and science skills were used.

To further explore this effect we also used an ordinal variable to measure the count of skills used. For instance we use the *arts_ord* variable, which is zero if no arts skills are used, and can be up to three if all three arts skills were reported as being used. We then use the same idea of *sci_ord*, which uses science skills. Our second specification, *skills_count*, considers the range of arts and science skills together for those firms that use both. This is then coded as zero for firms that do not report using an arts and a science skill, or two for firms that report one of each, up to six for those firms that report using all three science and all three arts skills.

For our dependent variables we use a number of measures of firm performance and innovation. We measure growth using log difference measures for the 2008-2010 and 2010-2012 periods for both employment and sales. The general forms for these measures are:

$$growth\_employment = \ln(employment\_t_{n+1}) - \ln(employment\_t_n)$$

$$growth\_sales = \ln(sales\_t_{n+1}) - \ln(sales\_t_n)$$

We measure labour productivity by dividing sales by employment, and calculate productivity growth as above. For innovation we use two different measures derived from UKIS, both of which refer to innovation outputs (i.e. commercialisation), as opposed to inputs (i.e. R&D). These include a measure of the percentage of a firm's turnover derived from products that are new-to-the-firm in the 2008-2010 period, and the percentage turnover derived from products that are new-to-market in the same period. The prior measure effectively captures firms' innovation adoption, while the latter captures more radical innovation.

We use a number of measures to control for potential explanatory factors contributing to firm performance. We control for age and employment, including the variables and their squared terms to control for the possibility that the relationship with age and size are nonlinear (i.e. increase and then decrease, or increase exponentially). We control for other innovation investment by capturing R&D intensity, the ratio of the firm's spending on R&D as a share of turnover. We control for non-innovation investment using a measure from UKIS of capital investment intensity, observing spending on capital goods as a share of turnover. We control for reported changes in organisational structure in the time period using a binary variable.

We also control for exporting behaviour, also using a binary variable. We use measures to proxy general human capital levels within the firm, specifically using UKIS measures of the percentage of employees who are STEM graduates and the proportion who are non-STEM graduates. Finally, we control for industry (using 1-digit SIC codes) and region (using UK Government Office Region codes).

2.2 METHOD

Our analysis uses descriptive, univariate and multivariate methods. The descriptive statistics presented in Tables 1-3 show the relative frequency of the skills configurations in the sample and the general population, and compare the means of our different variables by the various types of skills used. We also present correlation measures and tables of results to show the distribution of skills in our sample. Our multivariate analysis uses as its basis an OLS regression model,[20] with the growth measures listed in the previous section as the dependent variables, and with the skills measures and controls listed above as the independent variables. The OLS regressions used include heterskedastic robust standard errors.[21] In addition to these we also use a range of robustness checks, which are detailed in Section 3.3.

The exact interpretation of the results of our econometric estimations will depend on the nature of both dependent and independent variables. More specifically, when both dependent and independent variables are expressed in logarithmic terms, we interpret the different parameters as elasticity, so a 1 per cent increase in the independent variable will lead to a percentage variation of the dependent variable, approximately equal to the value of the estimated beta coefficient. When only the dependent variable is in log difference (i.e. the employment, sales and productivity growth equations) these are interpreted as semi-elasticity (when the regressor refers to levels). In the case of semi-elasticity, the interpretation will be the following: a one unit variation of the independent variable (in this case the only option as our key independent variable is binary[22]) will approximately lead to a $100*\hat{\beta}$ per cent variation of the dependent variable. Effectively, this means that a significant coefficient of 0.01 is approximately equivalent to a 1 per cent increase in the growth rate.[23]

3. RESULTS

3.1 DESCRIPTIVE RESULTS

The descriptive statistics are presented in Tables 1-3, with further detailed descriptives presented in the appendix. Table 1 shows the prevalence of these skills throughout the data captured in UKIS, and then in creative, high-tech and KIBS (knowledge-intensive business services) firms. From these, we see that approximately 28 per cent of firms in the sample use both arts and science skills,[24] and this proportion is roughly the same across the sectors studied. The use of arts skills alone is similar in creative industries to the rest of the economy, but higher than in high-tech or KIBS firms, while science skills alone are less prevalent in creative firms but similar in high-tech and KIBS firms as in the general economy. From these figures we can use frequency weightings from the UKIS dataset to estimate the overall contribution of 'fused' arts and science skills firms to the economy.[25] Our estimates show that there were 23,029 fused firms with more than ten employees in the economy at the time of sampling in early 2011, suggesting that firms using arts and science skills made up 11 per cent of these in the economy.[26] Our estimates suggest that these firms employed 3,547,300 people and generated turnover of £552 billion. This represented 22.56 per cent of employment and 22.0 per cent of turnover among firms with more than ten employees. (Table 2 breaks these skills down using an alternative, more detailed OECD sectoral definitions. This again shows the relative prevalence of combined arts-science skills; for instance more than 30 per cent of low-tech firms use both arts and science skills.)

Table 3 presents the means and standard deviations for the main variables; a longer version of these tables is presented in the Appendix A.1 and A.2. We see that fused firms are on average larger, with a mean employment of 431 compared to a population average of 268 (though this would be expected if large firms are more likely to require a broader range of skills as a function of their size – something that will be examined in more detail later). We find that on average, fused firms invest 35 per cent of their turnover on R&D spending, but spend 3 per cent less of their annual turnover on capital assets than fused firms. On average, 51 per cent of fused firms export, more than any other group. The average fused firm has 11 per cent of its workforce as graduates with fused backgrounds and 14 per cent as graduates from other backgrounds. The growth rates for fused firms are also higher (though the interpretation of this figure is less straightforward).

Tables 4 and 5 provide further descriptive information. Table 4 lists a correlation matrix for the main independent variables. The results, which are all significant due to the large numbers of observations, do not present many surprising results, other than to emphasise the apparently strong relationship between exporting and skills. Table 5 shows a tabulation table for the six skills covered in the survey. This shows the proportion of each skill set that is combined with another skill set. The findings here show that even though arts skills are more likely to be present alongside other arts skills, and science skills alongside other science skills, there is significant 'crossover' with, for example, around 23 per cent of firms with mathematics skills having graphic design skills.

We also present in Figures 1a-d box plots for employment and sales growth over two periods for the skills categories. From these we see little evidence for meaningful differences in distributions between categories, suggesting that outliers in the data are not a consideration.

3.2 MULTIVARIATE RESULTS

Our multivariate results are presented in Tables 6-12. The results in Table 6 list use a series of firm performance measures. Models 1 and 2 are based on growth rates for employment and sales during the 2008-10 period covered by the survey. The overall goodness of fit of the models is low, as found in the wider literature. In model 1, however, STEM companies other things being equal experienced faster employment growth (5 per cent higher), as did companies with a higher percentage of science graduates in their workforce. Model 2 similarly shows that STEM firms experienced faster sales growth (6 per cent higher).

Models 3 and 4 examine the period 2010-2012. Now, we see that fused firms, other things being equal, show 6 per cent higher employment growth and 8 per cent higher sales growth. We also see evidence over this period that investment in capital goods is associated with growth, as is the adoption of new organisational structures. This is particularly relevant as it suggests that the benefits of investment in assets and organisational innovation is only realised later in the time period. Whereas for the earlier period (Model 1) there is a positive association between employment of science graduates and employment growth, in Model 3 the effect is negative – an unexpected finding that warrants further study.[27]

Models 5 and 6 present results for new-to-market (i.e. radical) and new-to-firm (i.e. incremental) innovations. We see that fused firms on average generate 3 per cent more of their sales from new-to-market innovations, and 4 per cent more of their sales from new-to-firm innovations. We also see that exporting, new organisational structure, and fused skills are all positively associated with the introduction of new-to-market innovations. Lastly, Models 7 and 8 present productivity in 2010 and productivity growth over the 2008-2010 period.[28] We see that science and combined arts and science skills are associated with a higher level of firm productivity, but not necessarily productivity growth. Productivity growth is more associated with exporting and investment in capital goods.

Tables 7, 8, and 9 explores how these findings vary across creative industries, high-tech firms and KIBS respectively. We find that the overall fused effect remains positive, but the interaction between fused and industry are mixed. In particular, Table 7 shows mixed effects for the high-tech dummy and the interaction term between the fused and high-tech. This is likely due to the relatively high concentration of fused skills in this sector, suggesting that there may be decreasing returns once fused skills are acquired if this is the norm in a sector. This particular issue is less prominent in Tables 8 and 9, where again the overall fused effect is positive but industry-specific interaction terms are not significant or weakly positive. This suggests that the overall effect is consistent but not specifically strong in these sectors.

As an alternative to our size controls in our standard models, we present in Tables 10 and 11 results for small (10-50 employees), medium (50-250) and large (250+) firms. In this case we see that the effects identified above remain strong even in smaller firms, and that the effect remains with medium-sized firms but is not significant with large firms, likely because most larger firms have these skills anyway.

Further to these findings, we also explored the additive effects of a number of different arts or science skills, so in other words whether firms with a range of arts skills or science skills outperform those with narrower skills. The results in Table 12 show that among firms that combine arts and science skills, addition of additional skills is associated with higher growth and innovation.

HEADLINE SUMMARY OF PERFORMANCE BENEFITS FOR SKILLS CONFIGURATIONS

	Arts Skills Only	STEM Skills Only	Arts and STEM Skills
Employment growth 2008-10	+3%	+5%*	+4%
Sales growth 2008-10	-1%	+6%*	+4%
Employment growth 2010-12	-1%	+4%	+6%**
Sales growth 2010-12	+1%	0%	+8%***
% Sales new-to-market Innovation	0%	+1%	+3%***
% Sales new-to-firm Innovation	+1%**	+1%**	+4%***
Productivity 2010	-4%	+16%***	+10%***

Note: *Indicates significance at 0.10, ** at 0.05 and *** at 0.01

3.3 ROBUSTNESS CHECKS

To further validate our findings we carried out a number of robustness checks, the results of which are presented in the Appendix. First, we use probit models for arts, science, and arts and science skills combined (Tables A.12 – A.14) to explore the possibility of reverse causality – in other words, the possibility that high-growth or particularly innovative firms may be more likely to combine skills. Our findings suggest that growth, innovation and productivity are not predictive of the skills phenomena we observe. Another potential issue is possible positive multicollinearity between skills used and percentage of graduates in the firms' workforce, which could bias our reporting of skills. This was addressed in several ways: first through stepwise regressions that added variables of the main equation with each iteration (Appendix A.4) that show that controlling for percentage of graduates does not change the results for future employment and sales growth. If anything this further validates our finding.

Among the other robustness checks carried out, consider the possibility that past sales and employment growth impacts on subsequent growth by including a model that controls for past employment and sales growth (Appendix A.5), but again this does not change our main findings. Another check involves the links between innovation and sales growth. Because innovation is a contributing factor to employment and sales growth (particularly when considering panel data), it is possible that innovation levels could impact the growth outcome observed in our main model. Consequently we estimate a model controlling for innovation output measures (new-to-market and new-to-firm market share) in the models with sales, employment and productivity growth (Appendix A.6) as dependent variables, and again the results do not change.

Finally, we estimate a version of the model (Appendix A.7) excluding firms that replied to the survey saying that they used all six skills, as a means of avoiding potential response-style bias (i.e. firms answering 'yes' to all questions), but the results are again consistent.

4. DISCUSSION

The results outlined above present a complex but intriguing picture of the relationship between skills combinations and firm performance. It has already been established in the previous literature that STEM skills are associated with business innovation and growth, but our findings indicate that there is a further benefit beyond these STEM skills associated with the combination of arts and science skills within an organisation. Importantly, while we find that STEM skills are associated with contemporaneous growth, we find that the combination of arts and science skills in an initial period only pays growth dividends in the following period. These findings are consistent with the possibility that the combination of arts and science skills may be a time-intensive process that necessitates organisational change and requires some time for the performance dividends to take effect. This interpretation is supported by our findings regarding delayed performance benefits associated with organisational change. This may also be one interpretation of our finding that while fused firms are more productive than the average firm, they are less productive than STEM firms in the time period studied. It remains a possibility that the dip in productivity is associated with the organisational change required to accommodate the creative skills that eventually give performance dividends.

Our results also show the apparent importance of these skills for business innovation. We find that arts and STEM skills alone are associated with the commercialisation of innovation, but that the combination of arts and science together are associated with the commercialisation of new-to-market innovations. These results complement previous findings on the importance of STEM skills and R&D to the innovation process, but also represent a new insight into the relevance of arts and creative skills, and on the importance of combining different types of skills. We also find some evidence of a link between the combination of these skills and the level of productivity. Our sector and size checks further give us a clear picture of performance dividends for those firms combining these skills. Even though it might be expected that larger firms would have a greater variety of skills, the benefits turn out to be greatest for smaller firms in areas outside the creative industries or other areas typically associated with creative skills.

Furthermore, our results indicate performance benefits also arise from the accumulation of multiple skills. Of the firms using both arts and science skills, those firms that use a broader range of skills are more likely to grow, are more innovative and are more productive. Our results show that the accumulation of skills remains a vital element contributing to firm performance, regardless of size or sector.

5. POLICY IMPLICATIONS AND CONCLUSION

The findings in this paper present an important and novel contribution to the evidence base regarding the importance of arts skills in the economy. Our analysis suggests that fused firms play a major role in the economy, employing some 3.5 million people and generating as much as £550 billion each year. Among firms with more than ten employees, the evidence suggests that fused firms make up 11 per cent of the population, but represent 22 per cent of employment and sales. Further, we find that whereas STEM skills and arts skills on their own are associated with stronger business performance, the combination of arts skills with STEM skills provides additional value. Firms that combine these skills show, other things being equal, higher sales and employment growth, and are more productive and innovative. At the same time, we also see that the benefits of skills accumulation may take resources, organisational change, and, importantly, time to come to fruition.

There are a number of possible policy implications that arise from our findings.

Firstly, previous research, such as the AHRC-funded Brighton Fuse project, showed the positive impact of investment in both arts and technical skills within the creative industries. Our research goes beyond this, demonstrating at the national level that these appear to be present in a broad range of other, ostensibly 'non-creative' sectors that utilise arts skills and combine them with technical expertise to generate superior firm performance – with a stronger effect in smaller firms. This adds further support to the view that creative activity in the wider creative economy – not just in the creative industries – should be the main focus for policymakers.[29]

Further, this research highlights the importance of arts skills to economic performance. Arts skills are rarely acknowledged as contributors to economic outcomes such as growth, productivity or innovation. Our study suggests that arts skills may play a quantitatively significant role in unlocking firm growth, lending support to the burgeoning global STEAM education movement, alongside more traditional calls for greater investment in the UK workforce's STEM skills.

As with all research, ours has a number of important limitations which must be borne in mind when interpreting the results. In particular, the UKIS data we have used is cross-sectional, so we have been unable to determine the marginal effect of a company's decision to add a particular skill on its subsequent performance (that is, we have been able to detect significant associations between skills investments and business performance, not causal relationships).[30] This is due to the fact that the skills questions used in this study were introduced in the 2010 wave of the UKIS, which ruled out use of the UKIS panel component for previous waves of the survey. Also, the structure of the data limits us, as we only know that a company accessed a skill, but not the magnitude of the investment or whether those skills were acquired inside or from outside the firm (one might reasonably expect the impacts on business performance and the nature of complementary investments to realise the value of the skills acquired to differ in these cases). We also face the challenge – common to all work on innovation surveys – of possible self-report response biases in our main questions. Whilst we are able to avoid self-response for our performance data in favour of 'harder' data from the BSD, this data source does have its own limitations.

The potential economic importance of our findings means that further research into skills combinations and business performance is warranted. Firstly, the use of panel data, particularly from the 2013 UKIS, should allow us to examine longitudinal skill factors on the mini-panel contained within each wave of the survey. This could go some way to tracking the performance implications of the accumulation of skills over time. We would also ideally like to find a way to use instrumental variable techniques to analyse this effect; this dataset does not contain an appropriate instrumental variable for our analysis, but other data sources or future UKIS iterations may make this possible. Further, the skills questions on UKIS were also introduced across Europe as part of the standard survey for the 2010 survey cycle. While not every European country chose to adopt these questions, they were introduced by a number of major European economies such as France, Italy and Sweden.[31] This introduces the possibility of testing the robustness of these UK findings by doing an international comparison of these effects in other economies. Ultimately, while CIS/UKIS data is useful, there remains considerable potential to explore this topic in more detail and to try to explain the benefits and complementarities arising from the combination of arts and science skills.

TABLE 1. **SAMPLE DISTRIBUTION ACCORDING ARTS AND STEM, STEM, ARTS, AND NEITHER ARTS NOR STEM FIRMS**

	All Firms		Creative Firms		High-Tech		Kibs	
	Freq	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**
No skills	4,111	45.51	326	51.99	758	51.36	981	58.01
Arts skills	1,175	13.01	78	12.44	70	4.74	99	5.85
STEM skills	1,136	12.58	51	8.13	235	15.92	206	12.18
Both arts and STEM	2,611	28.91	172	27.43	413	27.98	405	23.95
Total	**9,033**	**100**	**627**	**100**	**1476**	**100**	**1691**	**100**

TABLE 2. **SECTORAL DISTRIBUTION (BY MACRO CATEGORIES)/ROW PERCENTAGE**

	No skills		Arts skills		STEM		Skills both arts and STEM		Total
	Freq	Per cent	Freq	Per cent	Freq	Per cent	Freq	Per cent	
Residuals sectors	571	53.22	127	11.84	140	13.05	235	21.90	**1073**
Low tech	235	37.42	125	19.90	69	10.99	199	31.69	**628**
Med-low tech	244	37.71	94	14.53	116	17.93	193	29.83	**647**
Med-high tech	142	27.36	57	10.98	88	16.96	232	44.70	**519**
High tech	20	15.04	0	0.00	39	29.32	74	55.64	**133**
LKI market services and other	1,982	54.60	482	13.28	301	8.29	865	23.83	**3630**
Knowledge int. mkt services (excl. high)	734	46.72	205	13.05	214	13.62	418	26.61	**1571**
High tech knowledge intensive services	96	17.08	57	10.14	126	22.42	283	50.36	**562**
Know. int. fin. services + other KIS	87	32.22	28	10.37	43	15.93	112	41.48	**270**
Total	**4,111**	**45.51**	**1,175**	**13.01**	**1,136**	**12.58**	**2,611**	**28.91**	**9,033**

Residual sectors: mining and extraction - electricity, gas, steam and air conditioning - water supply (sewerage, waste management), construction.

Low tech: man. of food products, beverages, textiles, wearing apparel, leatherwood and cork (ex. furniture), paper and paper prod., reprod. of recorded media, man. of furniture, other manuf. (excl. medical and dental instr.).

Med-low tech: man. of recorder media, man. of coke and refined petroleum, products of rubber and plastic, products of other metallic mineral prod., man. of basic metals, man. of fabric. metal prod.(exc. machinery equipment and weapons), man. of ships and boats, repair and installation of mach. and equipment.

Med-high tech: man. of chemicals and chemical products, man. of electrical equipment, man. of machinery and equipment n.e.c, man. of motor vehicles trailers, man. of other transport equipment.

High tech: man. of basic pharmaceutical products, man. of computer electronic and optical products, man. of air and spacecraft machinery.

LKI market services and other: wholesale and retail trade and repair of motor veh. and motorcycles., wholesale trade except of motor vehicles and motorcycles, retail trade except of motor vehicles and motorcycles, land transport and transport via pipelines, warehousing and support activities for transportation, hotels and similar accommodations, food and beverages service activities, real estate activities, rental and leasing activities, services to buildings and landscape activities.

Knowledge int. mkt services(excl. high): water transport, air transport, legal and accounting activities, activities of head offices management. consultancy activities, architectural and engineering activities, advertising and market research, other professional scientific and technical activities, employment activities, security and investigation activities.

High tech knowledge intensive services: motion picture video and television. programme prod. recording, programming and broadcasting activities, telecommunications, Computer programming consultancy and related act., information services activities, scientific and research development.

Knw.int.fin. services +other KIS: financial service activities exc. insurance and pension funding, insurance reinsurance and pension funding, activities auxiliary to financial services and insurance act., Publishing activities.

TABLE 3. DESCRIPTIVE STATISTICS FOR SKILLS SUBSAMPLES (MEDIANS AND OBSERVATION DETAILS IN APPENDIX)

	Full Sample		No skills		Arts skills		Science skills		Arts and science skills	
	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
Age	18.69	11.89	19.09	11.84	19.25	11.4	19.02	11.24	18.86	11.72
Ln (age)	2.74	0.77	2.77	0.75	2.8	0.73	2.8	0.68	2.76	0.75
Ln (age)sq.	5.31	1.69	5.38	1.63	5.44	1.58	5.45	1.48	5.35	1.63
Size	268	1275.06	161.13	669.74	152.87	471.28	253.75	714.02	431.36	1560.62
Ln (size)	4.15	1.48	3.84	1.33	3.91	1.29	4.35	1.42	4.71	1.52
Ln (size) sq.	8.23	3.01	7.6	2.71	7.75	2.63	8.65	2.9	9.38	3.08
R&D intensity	0.15	3.32	0.01	0.29	0.02	0.5	0.28	3.66	0.35	5.51
Invest. tech. asset.	0.04	0.62	0.03	0.56	0.02	0.24	0.08	1.06	0.05	0.57
Exporter dummy	0.34	0.47	0.2	0.4	0.35	0.48	0.47	0.5	0.51	0.5
New org. structure	0.14	0.35	0.08	0.27	0.14	0.35	0.15	0.36	0.23	0.42
Prop staff STEM graduates	0.07	0.17	0.03	0.1	0.05	0.14	0.14	0.24	0.11	0.2
Prop staff other graduates	0.1	0.18	0.07	0.16	0.12	0.21	0.1	0.17	0.14	0.21
Empl. gr. 08-10(CIS)	0.2	0.58	0.17	0.59	0.17	0.52	0.23	0.53	0.25	0.62
Sales gr. 08-10(CIS)	0.17	0.6	0.14	0.58	0.16	0.58	0.21	0.65	0.24	0.62
Empl. gr.10-13(BSD)	0.03	0.5	0.02	0.48	0	0.47	0.04	0.49	0.1	0.54
Sales gr.10-13(BSD)	0.02	0.61	0.01	0.54	0.01	0.56	0.02	0.65	0.14	0.64
Prop sales NTM Inno	0.03	0.1	0.01	0.07	0.02	0.08	0.03	0.11	0.05	0.14
Prop sales NTF Inno	0.04	0.11	0.02	0.09	0.04	0.12	0.04	0.11	0.05	0.13
ln productivity	4.31	1.13	4.11	1.12	4.26	1.03	4.55	1.08	4.56	1.08
Product. growth	0.09	0.88	0.05	0.91	0.06	0.76	0.11	0.89	0.15	0.9

FIGURE 1a-d: **BOXPLOTS FOR DISTRIBUTION LOG GROWTH MEASURES**

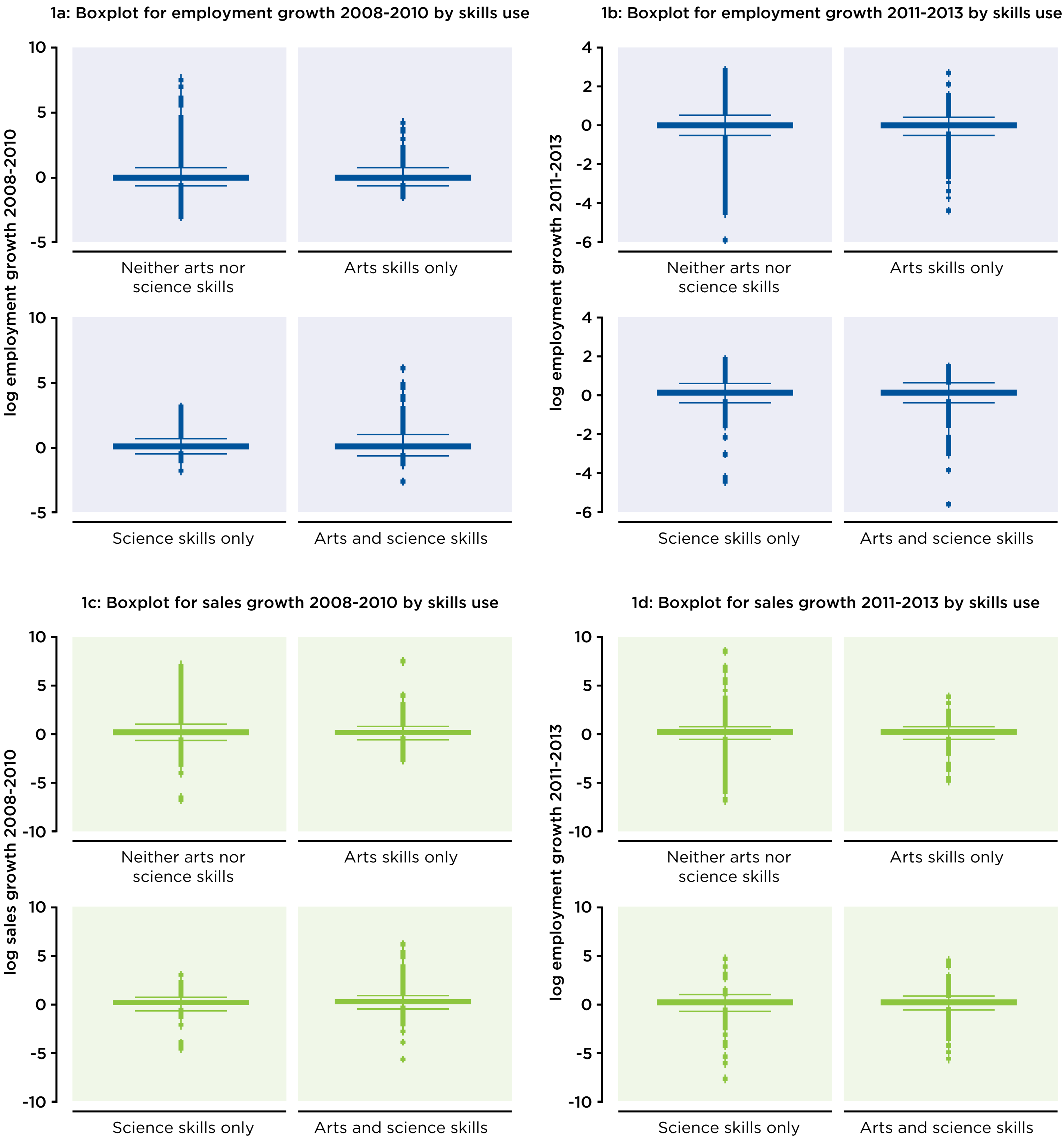

TABLE 4. **CORRELATION MATRIX (NUMBER OF OBSERVATIONS FOR EACH CELL:7388)**

	1	2	3	4	5	6	7	8	9	10
1 Ln (age)	1									
2 Ln (age)sq.	0.99960	1								
3 Ln (size)	0.12940	0.12960	1							
4 Ln (size) sq.	0.13070	0.13100	1	1						
5 R&D intensity	-0.02750	-0.02730	-0.01230	-0.01230	1					
6 Invest. tech. asset.	-0.03880	-0.03900	-0.01660	-0.01660	0.03380	1				
7 Exporter dummy	0.04830	0.04770	0.11290	0.11370	0.01430	0.00030	1			
8 New org. structure	-0.12260	-0.12220	0.05410	0.05380	-0.00520	0.00780	0.09770	1		
9 % Staff STEM	-0.08100	-0.07980	-0.00360	-0.00360	0.05240	0.04730	0.25550	0.12830	1	
10 % Staff other graduates	-0.06320	-0.06380	0.01190	0.01210	-0.00670	0.01980	0.12600	0.06720	0.10970	1

TABLE 5. **6X6 MATRIX FOR SKILLS CATEGORIES (BOLD INDICATES ALL FIRMS USING SKILL; FIGURE IN BRACKETS REPRESENTS PERCENTAGE OF SKILLS IN ITALICS ALSO USING BOLD SKILL) (ALL SIGNIFICANT AT 1% CONFIDENCE)**

	Graphic skills	Design skills	Multimedia skills	Software/ database skills	Engineering skills	Maths skills
Graphic skills	2,628 (100)	1155 (70,34)	2020 (72.25)	1640 (58.71)	692 (42.24)	601 (55.39)
Design skills	1155 (43.95)	1,642 (100)	1087 (38.97)	1023 (36.62)	740 (45.23)	451 (41.52)
Multimedia skills	2020 (76.66)	1087 (66.19)	2,832 (100)	1834 (65.66)	713 (43.52)	628 (57.88)
Software/database skills	1640 (62.38)	1023 (62.30)	1834 (65.66)	2,793 (100)	911 (55.61)	742 (68.38)
Engineer skills	692 (26.42)	740 (45.06)	713 (25.63)	911 (32.61)	1,638 (100)	599 (55.20)
Maths skills	601 (22.87)	451 (27.46)	628 (22.17)	742 (26.56)	599 (36.56)	1,085 (100)

TABLE 6. OLS ESTIMATES FOR EMPLOYMENT GROWTH, SALES GROWTH, INNOVATION AND PRODUCTIVITY

	(1) Empl. gr. 2008-2010 (BSD)	(2) Sales gr. 2008-2010 (BSD)	(3) Empl. gr. 2010-2012 (BSD)	(4) Sales gr. 2010-2012 (BSD)	(5) % Sales NTM innov	(6) % Sales NTF innov	(7) ln productivity 2010	(8) Product. growth 08-10
Arts skills	0.03 (0.03)	-0.01 (0.03)	-0.01 (0.02)	0.01 (0.03)	0.00 (0.00)	0.01** (0.01)	-0.04 (0.04)	-0.05 (0.05)
Science skills	0.05* (0.03)	0.06* (0.03)	0.04 (0.03)	0.00 (0.03)	0.01 (0.01)	0.01** (0.01)	0.16*** (0.05)	0.02 (0.05)
Arts and sc. skills	0.04 (0.03)	0.04 (0.03)	0.06** (0.02)	0.08*** (0.03)	0.03*** (0.01)	0.04*** (0.01)	0.10*** (0.04)	0.04 (0.05)
Ln(age)	5.50*** (1.20)	5.33*** (1.27)	2.00*** (0.76)	2.92*** (0.70)	0.15 (0.11)	0.19 (0.12)	-1.95*** (0.64)	4.88*** (1.44)
Ln(age)sq.	-2.72*** (0.57)	-2.62*** (0.60)	-0.97*** (0.36)	-1.41*** (0.33)	-0.07 (0.05)	-0.09* (0.05)	0.93*** (0.29)	-2.30*** (0.68)
Ln(size)	0.77 (0.85)	0.71 (0.84)	0.76 (0.72)	1.47* (0.76)	0.19 (0.12)	0.13 (0.14)	-2.97*** (1.11)	-0.05 (1.31)
Ln(size) sq. (0.41)	-0.34 (0.41)	-0.32 (0.35)	-0.37 (0.37)	-0.70* (0.06)	-0.10* (0.07)	-0.06 (0.54)	1.40*** (0.64)	0.04
R&D intensity	0.00 (0.00)	-0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.02* (0.01)	0.04** (0.02)
Invest. tech. asset.	0.02** (0.01)	-0.02 (0.02)	0.03*** (0.01)	0.03* (0.02)	0.00 (0.00)	-0.00 (0.00)	-0.07 (0.05)	0.07* (0.04)
Exporter dummy	0.01 (0.02)	0.03 (0.02)	-0.02 (0.02)	0.01 (0.03)	0.01** (0.01)	0.00 (0.00)	0.22*** (0.04)	-0.03 (0.04)
New org. structure	0.04 (0.03)	0.02 (0.03)	0.09*** (0.03)	0.12*** (0.03)	0.04*** (0.01)	0.06*** (0.01)	-0.01 (0.04)	0.01 (0.06)
% Staff STEM graduates	0.15* (0.09)	-0.02 (0.11)	-0.16* (0.09)	-0.06 (0.10)	0.06*** (0.02)	-0.00 (0.02)	0.10 (0.12)	0.10 (0.11)
% Staff other graduates	0.06 (0.06)	0.17** (0.07)	0.02 (0.07)	0.06 (0.08)	0.01 (0.01)	0.01 (0.01)	0.29*** (0.09)	0.08 (0.10)
Sectoral dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3,519	3,515	3,709	3,705	3,717	3,721	3,786	3,475
R sq.	0.17	0.15	0.07	0.09	0.14	0.11	0.42	0.06
R. sq.ad.	0.15	0.13	0.05	0.07	0.12	0.09	0.41	0.04

Notes: ***, ** and * indicate significance on a 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in brackets.

TABLE 7. OLS ESTIMATES: INCLUDING CONTROLS FOR HIGH-TECH FIRMS AND HIGH-TECH*COMBINED SKILLS INTERACTION TERM

	(1) Empl.gr. 2008-2010 (BSD)	(2) Sales gr. 2008-2010 (BSD)	(3) Empl. gr. 2010-2012 (BSD)	(4) Sales gr. 2010-2012 (BSD)	(5) % Sales NTM innov	(6) % sales NTF innov	(7) ln productivity 2010	(8) Product. growth 08-10
Arts skills	0.04 (0.03)	-0.00 (0.03)	-0.01 (0.02)	-0.00 (0.03)	-0.00 (0.00)	0.02*** (0.01)	0.05 (0.04)	-0.07 (0.04)
Science skills	0.05* (0.03)	0.07** (0.03)	0.04 (0.03)	0.01 (0.03)	0.01 (0.01)	0.01** (0.01)	0.29*** (0.05)	0.01 (0.05)
Arts and sc. skills	0.04* (0.03)	0.05* (0.03)	0.06*** (0.02)	0.09*** (0.03)	0.03*** (0.01)	0.04*** (0.01)	0.25*** (0.04)	0.02 (0.04)
Arts and sci*ht	-0.18 (0.17)	-0.09 (0.14)	-0.18** (0.08)	-0.41** (0.21)	0.02 (0.06)	-0.04 (0.04)	0.20 (0.26)	0.07 (0.22)
Ln(age)	4.94*** (1.18)	4.82*** (1.26)	1.95*** (0.75)	2.97*** (0.69)	0.10 (0.11)	0.17 (0.13)	0.16 (0.72)	4.99*** (1.41)
Ln(age)sq.	-2.46*** (0.56)	-2.38*** (0.60)	-0.95*** (0.35)	-1.43*** (0.32)	-0.05 (0.05)	-0.08 (0.06)	0.02 (0.33)	-2.35*** (0.66)
Ln(size)	0.56 (0.84)	0.41 (0.84)	0.66 (0.69)	1.51** (0.75)	0.18 (0.12)	0.14 (0.14)	-3.80*** (1.28)	0.19 (1.28)
Ln(size) sq.	-0.24 (0.41)	-0.17 (0.41)	-0.32 (0.34)	-0.72** (0.36)	-0.09 (0.06)	-0.07 (0.07)	1.75*** (0.63)	-0.08 (0.63)
R&D intensity	0.00 (0.00)	-0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.02* (0.01)	0.04** (0.02)
Invest. tech. asset.	0.02** (0.01)	-0.02 (0.02)	0.03*** (0.01)	0.03* (0.02)	0.00 (0.00)	-0.00 (0.00)	-0.08* (0.05)	0.07* (0.04)
Exporter dummy	0.02 (0.02)	0.05** (0.02)	-0.01 (0.02)	0.03 (0.02)	0.01** (0.00)	0.00 (0.00)	0.42*** (0.04)	-0.03 (0.04)
New org. structure	0.04 (0.03)	0.04 (0.04)	0.10*** (0.03)	0.12*** (0.03)	0.04*** (0.01)	0.06*** (0.01)	-0.00 (0.05)	0.01 (0.06)
% Staff STEM graduates	0.10 (0.08)	0.05 (0.11)	-0.11 (0.08)	-0.05 (0.10)	0.08*** (0.02)	-0.00 (0.02)	0.10 (0.12)	0.18 (0.13)
% Staff other graduates	0.02 (0.06)	0.10 (0.07)	-0.00 (0.07)	0.05 (0.07)	0.00 (0.01)	0.01 (0.01)	0.43*** (0.09)	0.09 (0.10)
High tech dummy	-0.23* (0.13)	-0.24 (0.37)	0.18 (0.24)	0.55*** (0.21)	0.00 (0.02)	0.03 (0.03)	-0.14 (0.30)	0.11 (0.12)
Sectors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3,519	3,515	3,709	3,705	3,717	3,721	3,786	3,475
R sq.	0.16	0.11	0.05	0.07	0.12	0.09	0.20	0.05
R. sq.ad.	0.15	0.10	0.04	0.06	0.11	0.08	0.20	0.04

Notes: ***, ** and * indicate significance on a 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in brackets.

TABLE 8. OLS ESTIMATES: INCLUDING CONTROLS FOR KIBS FIRMS AND KIBS*COMBINED SKILLS INTERACTION TERM

	(1) Empl. gr. 2008-2010 (BSD)	(2) Sales gr. 2008-2010 (BSD)	(3) Empl. gr. 2010-2012 (BSD)	(4) Sales gr. 2010-2012 (BSD)	(5) % Sales NTM innov	(6) % Sales NTF innov	(7) ln productivity 2010	(8) Product. growth 08-10
Arts skills	0.04 (0.03)	-0.00 (0.03)	-0.01 (0.02)	-0.00 (0.03)	-0.00 (0.00)	0.02*** (0.01)	0.06 (0.04)	-0.07 (0.04)
Science skills	0.06** (0.03)	0.07** (0.03)	0.04 (0.03)	0.02 (0.03)	0.01 (0.01)	0.02** (0.01)	0.30*** (0.05)	0.01 (0.05)
Arts and sc. skills	0.00 (0.03)	0.05 (0.03)	0.05** (0.02)	0.06** (0.03)	0.03*** (0.01)	0.03*** (0.01)	0.22*** (0.05)	0.03 (0.05)
Arts and sci*ht	-0.18 (0.17)	-0.09 (0.14)	-0.18** (0.08)	-0.41** (0.21)	0.02 (0.06)	-0.04 (0.04)	0.20 (0.26)	0.07 (0.22)
Arts sci*kibs	0.12** (0.06)	0.03 (0.06)	0.05 (0.05)	0.09 (0.06)	-0.01 (0.01)	0.03* (0.01)	0.12 (0.08)	0.00 (0.09)
Ln(age)	4.93*** (1.18)	4.81*** (1.26)	1.96*** (0.75)	2.98*** (0.69)	0.10 (0.11)	0.17 (0.13)	0.18 (0.72)	4.99*** (1.41)
Ln(age)sq.	-2.46*** (0.56)	-2.38*** (0.60)	-0.95*** (0.35)	-1.44*** (0.32)	-0.05 (0.05)	-0.09 (0.06)	0.01 (0.33)	-2.35*** (0.66)
Ln(size)	0.53 (0.84)	0.40 (0.84)	0.65 (0.69)	1.50** (0.74)	0.18 (0.12)	0.14 (0.14)	-3.82*** (1.28)	0.19 (1.28)
Ln(size) sq.	-0.22 (0.41)	-0.17 (0.41)	-0.32 (0.34)	-0.72** (0.36)	-0.09 (0.06)	-0.07 (0.07)	1.75*** (0.63)	-0.08 (0.63)
R&D intensity	0.00 (0.00)	-0.01* (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.02* (0.01)	0.04** (0.02)
Invest. tech. asset.	0.02** (0.01)	-0.02 (0.02)	0.03*** (0.01)	0.03* (0.02)	0.00 (0.00)	-0.00 (0.00)	-0.08* (0.05)	0.07* (0.04)
Exporter dummy	0.02 (0.02)	0.05** (0.02)	-0.01 (0.02)	0.03 (0.02)	0.01** (0.00)	0.00 (0.00)	0.42*** (0.04)	-0.03 (0.04)
New org. structure	0.04 (0.03)	0.04 (0.04)	0.10*** (0.03)	0.12*** (0.03)	0.04*** (0.01)	0.06*** (0.01)	-0.00 (0.05)	0.01 (0.06)
% Staff STEM graduates	0.08 (0.08)	0.05 (0.11)	-0.12 (0.08)	-0.07 (0.10)	0.08*** (0.02)	-0.01 (0.02)	0.08 (0.12)	0.18 (0.13)
% Staff other graduates	0.01 (0.06)	0.10 (0.07)	-0.01 (0.06)	0.05 (0.07)	0.00 (0.01)	0.00 (0.01)	0.42*** (0.09)	0.09 (0.10)
KIBS dummy	-0.21* (0.12)	-0.30 (0.37)	0.05 (0.24)	0.18 (0.11)	0.00 (0.01)	0.00 (0.02)	-0.44* (0.24)	(0.08)
Sectors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3,519	3,515	3,709	3,705	3,717	3,721	3,786	3,475
R sq.	0.16	0.11	0.05	0.07	0.12	0.09	0.20	0.05
R. sq.ad.	0.15	0.10	0.04	0.06	0.11	0.08	0.20	0.04

Notes: ***, ** and * indicate significance on a 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in brackets.

TABLE 9. **OLS ESTIMATES: INCLUDING CONTROLS FOR CREATIVE INDUSTRIES FIRMS AND CREATIVE INDUSTRIES*COMBINED SKILLS INTERACTION TERM**

	(1) Empl.Gr. 2008-2010 (BSD)	(2) Sales Gr. 2008-2010 (BSD)	(3) Empl.Gr. 2010-2012 (BSD)	(4) Sales Gr. 2010-2012 (BSD)	(5) % Sales NTM Innov	(6) % Sales NTF Innov	(7) ln Productivity 2010	(8) Product. growth 08-10
Arts skills	0.04 (0.03)	0.00 (0.03)	-0.01 (0.02)	0.00 (0.03)	0.00 (0.00)	0.02*** (0.01)	0.04 (0.04)	-0.07 (0.04)
Science Skills	0.06** (0.03)	0.08** (0.03)	0.04 (0.03)	0.02 (0.03)	0.01 (0.01)	0.01** (0.01)	0.29*** (0.05)	0.01 (0.05)
Arts and Sc. skills	0.04 (0.03)	0.04 (0.03)	0.06*** (0.02)	0.08*** (0.03)	0.03*** (0.01)	0.04*** (0.01)	0.25*** (0.04)	0.03 (0.04)
ArtsSci* Creat. Ind.	0.07 (0.10)	0.26* (0.14)	-0.02 (0.13)	0.16 (0.14)	0.01 (0.02)	0.06* (0.03)	-0.05 (0.14)	-0.03 (0.15)
Ln(Age)	4.90*** (1.18)	4.83*** (1.26)	1.94** (0.76)	2.98*** (0.69)	0.10 (0.11)	0.18 (0.13)	0.11 (0.72)	4.99*** (1.41)
Ln(Age)sq.	-2.44*** (0.56)	-2.38*** (0.59)	-0.95*** (0.35)	-1.44*** (0.32)	-0.05 (0.05)	-0.09 (0.06)	0.04 (0.33)	-2.35*** (0.66)
Ln(Size)	0.56 (0.84)	0.41 (0.84)	0.66 (0.69)	1.51** (0.74)	0.18 (0.12)	0.14 (0.14)	-3.81*** (1.28)	0.19 (1.28)
Ln(Size) sq.	-0.24 (0.41)	-0.17 (0.41)	-0.32 (0.34)	-0.72** (0.36)	-0.09 (0.06)	-0.07 (0.07)	1.75*** (0.62)	-0.08 (0.63)
R&D intensity	0.00 (0.00)	-0.01* (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.02* (0.01)	0.04** (0.02)
Invest. Tech. asset.	0.02** (0.01)	-0.02 (0.02)	0.03*** (0.01)	0.03* (0.02)	0.00 (0.00)	-0.00 (0.00)	-0.07 (0.05)	0.07* (0.04)
Exporter dummy	0.02 (0.02)	0.05** (0.02)	-0.01 (0.02)	0.03 (0.02)	0.01** (0.00)	0.00 (0.00)	0.41*** (0.04)	-0.03 (0.04)
New org. structure	0.04 (0.03)	0.04 (0.04)	0.10*** (0.03)	0.12*** (0.03)	0.04*** (0.01)	0.06*** (0.01)	-0.00 (0.05)	0.01 (0.06)
% Staff STEM Graduates	0.11 (0.08)	0.04 (0.11)	-0.11 (0.08)	-0.05 (0.10)	0.08*** (0.02)	-0.01 (0.02)	0.06 (0.12)	0.17 (0.13)
% Staff Other Graduates	0.03 (0.06)	0.11 (0.07)	0.00 (0.07)	0.06 (0.07)	0.00 (0.01)	0.01 (0.01)	0.41*** (0.09)	0.09 (0.10)
Creative Ind. dummy	-0.06 (0.08)	-0.06 (0.11)	-0.03 (0.07)	-0.11 (0.09)	-0.02* (0.01)	-0.00 (0.02)	0.31*** (0.10)	0.05 (0.08)
Sectors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3,519	3,515	3,709	3,705	3,717	3,721	3,786	3,475
R sq.	0.16	0.11	0.05	0.07	0.12	0.09	0.21	0.05
R. sq.ad.	0.15	0.10	0.04	0.06	0.11	0.08	0.20	0.04

Notes; ***, ** and * indicate significance on a 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in brackets.

TABLE 10. **OLS ESTIMATES BY SIZE CATEGORIES: 10-5-, 50-250**

	10-50						50-250					
	(1) Sales 08-10 (BSD)	(2) Employment 08-10 (BSD)	(3) Employment 10-13 (BSD)	(4) Sales 10-13 (BSD)	(5) % Sales NTM innovation	(6) % Sales NTF innovation	(7) Sales 08-10 (BSD)	(8) Employment 08-10 (BSD)	(9) Employment 10-13 (BSD)	(10) Sales 10-13 (BSD)	(11) % Sales NTM innovation	(12) % Sales NTF innovation
Arts skills	-0.07 (0.09)	-0.00 (0.03)	-0.00 (0.03)	-0.06 (0.04)	0.36 (0.45)	1.11 (0.69)	-0.08 (0.18)	-0.02 (0.08)	-0.02 (0.08)	-0.01 (0.09)	-0.44 (0.41)	1.70** (0.83)
Science skills	0.07 (0.12)	0.05 (0.04)	-0.02 (0.04)	0.01 (0.06)	1.47 (0.91)	0.98 (0.83)	-0.07 (0.20)	-0.03 (0.09)	0.11 (0.07)	0.07 (0.07)	0.00 (0.60)	1.91* (0.99)
Arts and science skills	0.12 (0.10)	0.11*** (0.04)	0.06* (0.03)	0.09** (0.04)	4.08*** (0.80)	3.91*** (0.79)	0.10 (0.18)	0.11 (0.09)	0.13** (0.07)	0.13* (0.07)	1.29* (0.68)	3.43*** (1.06)
Ln (age)	0.00*** (0.00)	0.00*** (0.00)	0.00 (0.00)	0.00*** (0.00)	0.00** (0.00)	0.00 (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00** (0.00)	0.00*** (0.00)	-0.00 (0.00)	0.00* (0.00)
Ln (age) sq.	-0.68*** (0.06)	-0.24*** (0.02)	-0.05** (0.02)	-0.11*** (0.02)	-1.05*** (0.34)	-0.57** (0.28)	-1.17*** (0.13)	-0.63*** (0.07)	-0.15*** (0.05)	-0.20*** (0.04)	0.06 (0.35)	-2.03** (0.93)
Ln (size)	-6.49 (8.12)	7.28** (3.03)	4.18* (2.41)	4.18 (3.56)	60.07 (50.83)	-27.76 (52.71)	-50.17 (86.40)	47.15 (38.98)	53.79* (29.58)	-15.05 (34.71)	26.92 (287.05)	-134.46 (338.85)
Ln (size) sq.	3.12 (3.87)	-3.44** (1.44)	-2.01* (1.15)	-1.98 (1.69)	-29.16 (24.23)	12.71 (25.16)	25.16 (42.75)	-23.24 (19.29)	-26.61* (14.64)	7.49 (17.17)	-13.37 (141.92)	66.61 (167.68)
R&D intensity	0.00*** (0.00)	-0.00* (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	-0.01 (0.01)	-0.01 (0.02)	0.45 (0.38)	0.11 (0.13)
Invest technical assets	0.00*** (0.00)	0.00*** (0.00)	-0.00*** (0.00)	0.00*** (0.00)	-0.00 (0.00)	0.00 (0.00)	-0.02 (0.02)	-0.01 (0.01)	0.01 (0.01)	0.00 (0.01)	0.06 (0.07)	-0.15* (0.09)
Exports	-0.09 (0.09)	-0.02 (0.03)	0.03 (0.03)	0.08** (0.04)	0.80 (0.64)	0.27 (0.59)	0.10 (0.18)	0.01 (0.08)	0.07 (0.07)	0.06 (0.06)	1.40 (1.30)	-0.12 (0.80)
New org. structure	0.22* (0.11)	0.09** (0.04)	0.07* (0.04)	0.08 (0.05)	4.15*** (0.97)	5.78*** (1.09)	0.32 (0.27)	0.38*** (0.12)	0.10 (0.08)	0.11 (0.08)	3.29*** (1.22)	5.30*** (1.67)
% STEM grads	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.10*** (0.03)	-0.00 (0.02)	-0.01* (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	-0.02 (0.02)	-0.00 (0.03)
% Other grads	-0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.01 (0.02)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.02 (0.02)
Sectoral dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	2,695	2,696	2,631	2,631	2,657	2,659	830	830	824	824	815	817
R2	0.16	0.15	0.06	0.09	0.16	0.10	0.28	0.21	0.27	0.16	0.18	0.24
R2 adjusted	0.13	0.12	0.03	0.06	0.13	0.08	0.19	0.12	0.19	0.07	0.08	0.15

Notes: ***, ** and * indicate significance on a 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in brackets.

TABLE 11. **OLS ESTIMATES BY SIZE CATEGORIES: >250**

	More than 250					
	(1) Sales 08-10 (CIS)	(2) Employment (CIS)	(3) Employment (BSD)	(4) Sales 10-13 (BSD)	(5) % Sales NTM innovation	(6) % Sales NTF innovation
Arts skills	0.14 (0.42)	0.38 (0.25)	0.08 (0.17)	0.37** (0.14)	-1.57* (0.85)	3.18 (3.99)
Science skills	-0.45 (0.34)	-0.19 (0.21)	0.22 (0.15)	-0.25 (0.16)	-1.03 (0.68)	0.45 (2.47)
Arts and science skills	0.31 (0.50)	0.24 (0.26)	0.19 (0.17)	0.12 (0.13)	0.87 (0.89)	4.76** (2.40)
Ln (age)	-0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)
Ln (age) sq.	-0.13 (0.25)	-0.30** (0.15)	-0.10 (0.10)	-0.04 (0.08)	0.31 (0.31)	-2.11 (1.59)
Ln (size)	-470.07 (558.40)	-57.65 (308.39)	-188.73 (215.21)	-93.37 (139.13)	535.91 (1080.07)	1572.10 (2667.67)
Ln (size) sq.	234.97 (278.80)	28.97 (153.95)	94.26 (107.47)	46.63 (69.46)	-267.55 (539.27)	-785.62 (1331.63)
R&D intensity	0.12 (0.12)	0.03 (0.07)	-0.49*** (0.04)	-0.05 (0.04)	-0.17 (0.55)	-0.66 (0.96)
Invest tech. assets	0.04 (0.20)	-0.03 (0.13)	0.00 (0.05)	-0.05 (0.07)	0.18 (0.39)	1.25 (1.13)
Exports	-0.44 (0.52)	0.10 (0.29)	-0.15 (0.31)	0.25 (0.41)	0.59 (1.19)	-0.08 (2.68)
New org. structure	1.00* (0.60)	0.47 (0.34)	0.22 (0.16)	0.31* (0.16)	2.06 (1.47)	8.93** (3.69)
% STEM grads	-0.03* (0.02)	-0.01 (0.01)	-0.00 (0.01)	-0.01 (0.01)	0.03 (0.04)	0.08 (0.13)
% Other grads	-0.00 (0.03)	-0.02** (0.01)	-0.00 (0.00)	-0.00 (0.01)	0.01 (0.03)	-0.04 (0.07)
Sectoral dummies	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes
Obs	258	259	257	257	249	249
R sq.	0.28	0.21	0.27	0.16	0.18	0.24
R. sq.ad.	0.19	0.12	0.19	0.07	0.08	0.15

Notes: ***, ** and * indicate significance on a 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in brackets.

TABLE 12. OLS ESTIMATES USING COUNTS OF DIFFERENT SKILLS ORDINAL FIGURES FOR SKILLS

	(1) Empl. gr. 2008-2010 (BSD)	(2) Sales gr. 2008-2010 (BSD)	(3) Empl. gr. 2010-2012 (BSD)	(4) Sales gr. 2010-2012 (BSD)	(5) % Sales NTM innov	(6) % Sales NTF innov	(7) ln Productivity 2010	(8) Product. growth 08-10
Skills_count	0.01 (0.01)	0.01 (0.01)	0.01** (0.01)	0.02** (0.01)	0.01*** (0.00)	0.01*** (0.00)	0.03** (0.01)	0.02* (0.01)
Ln (age)	5.41*** (1.31)	5.53*** (1.40)	2.05** (0.84)	2.96*** (0.77)	0.24* (0.12)	0.24* (0.13)	-1.77** (0.70)	5.40*** (1.62)
Ln (age) sq.	-2.68*** (0.62)	-2.71*** (0.66)	-1.00** (0.39)	-1.43*** (0.36)	-0.11** (0.06)	-0.11* (0.06)	0.84*** (0.32)	-2.54*** (0.76)
Ln (size)	0.61 (0.93)	0.74 (0.93)	0.53 (0.79)	1.85** (0.81)	0.28** (0.13)	0.15 (0.16)	-2.64** (1.18)	-0.55 (1.42)
Ln (size) sq.	-0.26 (0.45)	-0.33 (0.45)	-0.25 (0.38)	-0.89** (0.40)	-0.14** (0.06)	-0.08 (0.08)	1.24** (0.58)	0.28 (0.70)
R&D intensity	0.01 (0.00)	-0.01* (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.02* (0.01)	0.04* (0.02)
Invest. Tech. asset.	0.01** (0.01)	0.00 (0.01)	0.03*** (0.01)	0.03 (0.02)	0.00 (0.00)	-0.00 (0.00)	-0.05 (0.04)	0.07 (0.05)
Exporter dummy	0.01 (0.03)	0.01 (0.03)	-0.03 (0.03)	0.03 (0.03)	0.01 (0.01)	0.00 (0.01)	0.24*** (0.04)	-0.06 (0.05)
New org. structure	0.03 (0.03)	0.01 (0.04)	0.10*** (0.03)	0.11*** (0.04)	0.04*** (0.01)	0.06*** (0.01)	-0.03 (0.05)	0.02 (0.06)
% Staff STEM graduates	0.11 (0.10)	-0.02 (0.13)	-0.11 (0.10)	-0.08 (0.12)	0.06** (0.03)	0.00 (0.02)	0.17 (0.14)	0.11 (0.13)
% Staff other graduates	0.03 (0.07)	0.17** (0.08)	-0.01 (0.07)	0.05 (0.08)	0.00 (0.01)	0.01 (0.02)	0.26*** (0.10)	0.06 (0.12)
Sectoral dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	2,949	2,946	3,115	3,114	3,125	3,129	3,184	2,910
R sq.	0.17	0.16	0.08	0.09	0.15	0.11	0.42	0.07
R. sq.ad.	0.14	0.14	0.05	0.07	0.13	0.09	0.41	0.04

Notes: ***, ** and * indicate significance on a 1 per cent, 5 per cent and 10 per cent level, respectively. Standard errors in brackets.

ENDNOTES

1. This work was based on data from UK Community Innovation Survey (UKIS) and Business Structure Database (BSD), produced by the Office for National Statistics (ONS) and supplied by the Secure Data Service at the UK Data Archive. The data are Crown Copyright and reproduced with the permission of the controller of HMSO and Queen's Printer for Scotland. The use of the data in this work does not imply the endorsement of ONS or the Secure Data Service at the UK Data Archive in relation to the interpretation or analysis of the data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. The authors would like to thank Nesta for its support of the project and Juan Mateos Garcia, Hasan Bakhshi, Neil Lee, John Davies, George Windsor, Marc Cowling and Paul Nightingale for feedback and insights.
2. BIS (2014) Industrial Strategy Progress report. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/306854/bis-14-707-industrial-strategy-progress-report.pdf
3. ibid.
4. Coad, A. et al. (2014) UK Innovation Survey: Highly Innovative Firms and Growth. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/289234/bis-14-643-uk-innovation-survey-highly-innovative-firms-and-growth.pdf
5. A point that is broadly empirically supported - see Chevalier, A. (2011) Subject choice and earnings of UK Graduates. 'Economics of Education Review.' 30:6 1187-1201.
6. See DCMS (2016) 'Creative Industries Economic Estimates.' Available at: https://www.gov.uk/government/publications/creative-industries-economic-estimates-january-2016/creative-industries-economic-estimates-january-2016-key-findings
7. A very good overview of work in this area may be found in Sawyer, R. (2011) 'Explaining Creativity: The science of human innovation.' Oxford: Oxford University Press. See also Nissani, M. (1997) Ten cheers for interdisciplinarity: The case for interdisciplinary knowledge and research. 'Social Science Journal.' 34(2) 201-216; and Yong, et al. (2014) Conflict and creativity in interdisciplinary teams. 'Small Group Research.' 45(3) 266-289.
8. Brighton FUSE (2013) 'Brighton FUSE Final Report.' Available at: http://www.brightonfuse.com/wp-content/uploads/2013/10/The-Brighton-Fuse-Final-Report.pdf; Brighton FUSE 2 (2015) 'Freelancers in the Creative Digital IT Economy.' Available at: http://www.brightonfuse.com/wp-content/uploads/2015/01/brighton_fuse2_online.pdf
9. See: www.stemtosteam.org; Creative Industries Council (2014) CREATE_UK. http://www.thecreativeindustries.co.uk/media/243587/cic_report_final-hi-res-.pdf; Nesta (2015) 'The Creative Economy and the Future of Employment.' London: Nesta. Available at: https://www.nesta.org.uk/publications/creative-economy-and-future-employment
10. See also Cunningham, S. (forthcoming) Securing Australia's Future 10 – Capabilities for Australian Enterprise Innovation.
11. Statistical details for UKIS may be found at: http://discover.ukdataservice.ac.uk/catalogue?sn=6699, while a copy of the questionnaire may be found at: http://doc.ukdataservice.ac.uk/doc/6699/mrdoc/pdf/6699questionnaire_2008_2010.pdf.
12. Because not all respondents answered every question, the number of observations seen in our subsequent analysis does not necessarily fully match this figure. Missing values are indicated in the descriptive statistics in the Appendix.
13. More information available at: http://discover.ukdataservice.ac.uk/catalogue?sn=6697
14. This is important because there may be delays in updating these figures. For instance, supposing the 'snapshot' for the BSD was 'taken' on 1st October 2013, if a company were to file its 2012-13 results on 2nd October 2013 the sales and employment figures would be the same for the 2013 BSD as for the 2012 BSD; the 'snapshot' records all values at the point in time, whether they are timely or not. Fortunately this does not appear to be common – a more common problem, albeit one not observed here, is that companies that cease trading may not always be observed at the time they cease trading if time passes before the legal entity is dissolved. Consequently, due to the 'snapshot' nature of the dataset, a company may have failed but still be listed with turnover and sales identical to its final filing.
15. This is a common problem in projects that involve linking of different datasets, particularly involving the BSD. We have investigated the linking issues and present comparison statistics between the matched and unmatched CIS data in Appendix A.XX.
16. The statistical note for this definition is available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/394668/Creative_Industries_Economic_Estimates_-_January_2015.pdf. The sectors classed as creative industries include: Advertising (SIC 2007 = 7021, 7311, 7312); Crafts (3212); Design (7410); TV and Radio (5911, 5912, 5913, 5914, 6010, 6020, 7420); Software (5821, 5829, 6201, 6202); Publishing (5811, 5812, 5813, 5814, 5819, 7430); Museums (5812); and Performing and Visual Arts (5920, 85520, 90010, 90020, 90030, 90040)
17. This may be found in the appendix at http://ec.europa.eu/research/innovation-union/pdf/knowledge_intensive_business_services_in_europe_2011.pdf
18. Nesta (2015) The geography of the UK's creative and high tech economies http://www.nesta.org.uk/sites/default/files/geography_uks_creative_high-tech_economieswv20151.pdf
19. See the links in notes 16 and 17 – the comparison shows how the Nesta definition classes broader groups than the OECD definition.
20. In the case of dependent variables measured as percentages (e.g. percentage turnover derived from new to market/firm innovations), other methods such as Tobit analysis may generally be more appropriate to account for the censoring of the variable. We have tried a number of other methods on our core model using these dependent variables and have found results that are consistent with the findings from OLS. For the purpose of consistency in interpretations of our results we present and discuss the OLS findings with the above caveat and are happy to share the other results upon request.
21. We include a plot of predicted probabilities for these heteroskedastic standard errors in Appendix A.XX
22. For more detailed discussions on the interpretation of dummy variables in semilogarithmic models, see Kennedy, P. E. (1981) Estimation with correctly interpreted dummy variables in semilogarithmic equations. 'American Economic Review.' 71, 801, and Giles, D.E. (2011) 'Interpreting dummy variables in semi-logarithmic regression models: Exact distributional results. No. 1101.' Department of Economics, University of Victoria.

23. Technically, the interpretation of a loglinear coefficient is that a one unit increase in X multiplies the expected value of Y by e $\hat{\beta}$. However for small values of $\hat{\beta}$, approximately e $\hat{\beta}$ ffi 1+ $\hat{\beta}$. (see Benoit, K. (2011) ‘Linear regression models with logarithmic transformations.’ London: London School of Economics. The relationship between the coefficient and the interpretation is consistent except for very large growth rates, and even in that case any changes are likely to be negligible (Coad, A. and Tamvada, J.P. (2012) Firm growth and barriers to growth among small firms in India. ‘Small Business Economics.’ 39.2 (2012): 383-400.
24. The difference between the sample and the population estimated in the weightings reflects the majority of firms in sectors with relatively little innovative activity.
25. These weightings are only able to be used for indicative descriptive statistics because the lack of complete performance data for 2008 means that the weighting no longer applies to the entire population. To calculate the weighted values, we multiply the value of the performance variable by the weight, and aggregate across the population.
26. Our estimates for the population are derived from the ONS population estimate of firms with more than ten employees for early 2011. (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32506/12octoberbusiness_20population_20estimates_20for_20the_20uk_20and_20regions_202011_20edition_20publication_20_20steven_20white_20_20august_202011.pdf). The UKIS excludes agriculture, mining and related firms (the ‘ABDE industries’ in official documentation), and the estimates in the above document re-introduces these so the picture is the most accurate.
27. One potential explanation of this finding may be Edith Penrose’s (1959) argument that after a period of growth firms need to allow time for new staff and organisational processes to settle. Recent empirical work on firm growth (e.g. Holzl 2014, Daunfeldt and Halvarsson 2015) supports this general notion, as does our positive finding for a link between organisational change and subsequent performance, but further work would be required for a conclusive discussion of this phenomenon.
28. Our findings on the absence of an effect for productivity growth appear to be due to noise in turnover growth figures; for the sake of brevity we do not include the non-significant findings for 2010-2012 period but are happy to provide them upon request.
29. Nesta (2013) ‘A Manifesto for the Creative Economy.’ London: Nesta. Available at: http://www.nesta.org.uk/publications/manifesto-creative-economy
30. Specifically, there is the risk of reverse causality (i.e. that companies that are particularly creative and fast-growing are more likely to have a range of creative skills on staff) or of unobserved heterogeneity that is associated with both skills investment and firm performance. We include control variables we can to minimise the risk of unobserved heterogeneity, and a probit model to check reverse causality; these techniques aim to reduce these risks, but they cannot eradicate them.
31. Denisova, E. (2013) ‘Final Report on ESSLait Metadata Repository.’ Luxembourg: Eurostat. Available at: http://ec.europa.eu/eurostat/documents/341889/725524/2013-esslait-metadata-final.pdf/887e8388-feaf-4410-b05c-18c89d2fa9cb

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