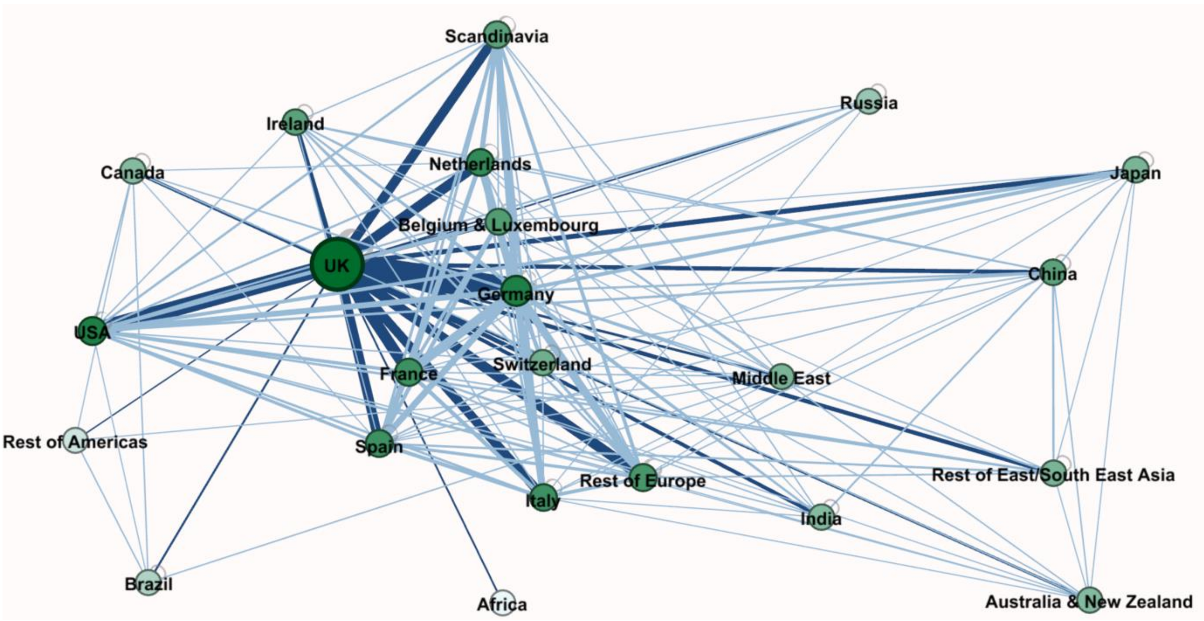
THE NATURE, LOCATION, AND FUNCTIONING OF INTERNATIONAL RESEARCH COLLABORATIONS

A study of manufacturing research

A study for the Department of Business, Innovation and Skills

Tomas Coates Ulrichsen & Charles Featherston



May, 2016

UNIVERSITY OF CAMBRIDGE

CSTI Science Technology Innovation Policy

The Nature, Location, and Functioning of International Research Collaborations: *A study of manufacturing research*

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Authors:
Tomas Coates Ulrichsen
Charles Featherston

Acknowledgements

The authors would like to thank Dr Nick Rousseau, former Head of International Innovation Strategy at the UK Department of Business, Innovation and Skills, for his involvement, insights, and support throughout the project. In addition, they would like to thank the group of academics that contributed invaluable insights and comments on early drafts of the survey, and all those that took the time to complete the final questionnaire. They would also like to thank the academics and policymakers that attended the workshop and contributed actively and generously to the discussions on the day.

Finally, the authors would like to thank Dr Eoin O'Sullivan for his extensive insights, advice and guidance throughout the project.

Project steering committee:

Dr Charles Featherston
Tomas Coates Ulrichsen
Dr Eoin O'Sullivan

Centre for Science, Technology and Innovation Policy

University of Cambridge

17 Charles Babbage Road

Cambridge

CB3 0FS

United-Kingdom

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Preface

There is a growing interest in international collaborations, which is fuelled by a combination of the need to find ways to stimulate global economic growth and the search for solutions to societal challenges that have global implications, such as climate change; antimicrobial resistance; and pressure on resources such as food, water, and raw materials.

Further, the UK Government is increasingly focused on international research and innovation collaboration's potential to deliver a wide range of beneficial outcomes from opening up new markets, attracting foreign investment, and building diplomatic relations and other partnerships with key global locations.

This means that, in many ways, much of our future will be materially affected by how successfully researchers and innovators are able to collaborate internationally.

A great variety of approaches to supporting international collaboration have been adopted reflecting different policy drivers, contexts, and governance structures. These will often focus on particular bilateral collaboration opportunities or the desire to do more with a given country to achieve a range of goals. One UK Government initiative, the Newton programme, which focuses on fifteen specific countries, aims to combine UK strengths with the local science and innovation base to address challenges being faced in one of those countries. These challenges are in areas such as urbanisation, healthcare, energy, and innovation capacity and capability.

The research described here is part of an attempt to look at international collaboration through a different lens. Innovate UK's decision to commission a review of the UK's High Value Manufacturing landscape provided an opportunity to look at international collaboration in terms of:

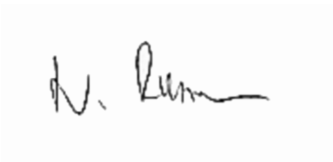
- What are the gaps in UK capability in terms of solving the big challenges facing high value manufacturing (HVM)?
- Where are the countries that have complementary gaps that might be close to finding the solutions?
- How can the UK build strategic partnerships that can offer clear value to all parties involved in terms of HVM growth?

This forward look required an understanding of current practice. The team at the University of Cambridge's Centre for Science, Technology, and Innovation Policy (CSTI) have carried out a survey and expert workshop of international collaboration to inform our understanding of practice amongst the UK manufacturing research community. This investigation addressed questions such as:

- Where are our main collaboration partner locations, and why are international partners involved?
- How are they being structured and what activities are partners contributing?
- What are the key barriers and enablers to the effective functioning of these international collaborations?
- What factors might we consider to ensure the UK secures real value from the new insights and technology arising from international manufacturing research collaborations?

To my knowledge this is the first study of its kind and sheds a powerful light on an area that has not been explored in this way. While the study focuses on manufacturing research, the insights and implications likely apply much more broadly, and the opportunity is there for others to follow with comparable studies in other research and innovation domains and explore the extent to which these findings apply more widely or are unique to manufacturing research.

The findings have wide relevance for Governments, funding bodies, and research institutions. I look forward to the debate that will follow and, hopefully, to a clearer understanding of what needs to be put in place for international collaboration projects to succeed in finding solutions to the many challenges we face.



Dr Nick Rousseau

Former Head of International Innovation Strategy
International Knowledge and Innovation Unit
Department of Business, Innovation and Skills

April 2016

Executive Summary

The many and varied benefits from collaborating internationally in research are well established. International research collaborations can have greater leveraged resources, better access to equipment and facilities (both specialised and large-scale) and access to expertise and know-how that may not be available nationally that will enable them to address key challenges of importance and economic value to the UK.

The *international manufacturing research collaborations* study for the UK Department of Business, Innovation and Skills critically examined:

- *where* UK academics involved in manufacturing research are collaborating
- *why* partners from different locations are brought into the collaborations
- *what* types of activities academic and industrial partners from different locations perform
- *what* factors act as barriers or enablers to making them work

It also explored the anticipated effects of international manufacturing research collaborations (IMRCs), crucially distinguishing between their contributions to different types of technologies important for technology development and deployment. It also explore the non-technology contributions made by IMRCs. The study additionally examined *what* factors may influence the equitable distribution of benefits and costs for all partners, and the likelihood of commercial exploitation of research outputs in the UK.

The study used the EPSRC Manufacturing the Future portfolio to represent UK-based manufacturing researchers. It drew on survey[1] and an expert workshop facilitated by the authors and hosted at the UK Department of Business, Innovation and Skills. The workshop explored in much greater detail the particular barriers and enablers to both starting international collaborations and their effective functioning, and the factors that might imbalance the distribution of benefits and costs between partners. The study developed a process and customisable methodology that can be replicated for other disciplines beyond manufacturing research.

Manufacturing research is an inherently multi-disciplinary research domain that is not easily defined. The study explored how manufacturing researchers define the field. They highlighted that manufacturing research is more than just how you make things and includes many of the activities that contribute to developing and exploiting major technological advances (including design, operations management, and services). In particular, they claimed that it is key to enabling technology-based concepts emerging from basic research to be scaled-up, and commercially deployed in the marketplace and deliver economic and social impacts.

Where in the world?

Collaborations involving research in these areas span a variety of locations around the world although a number of key hotspots emerge. In particular, when considering which locations were

[1] The survey secured 164 responses (17% response rate).

most important for realising project objectives, partners based in Germany, France and the US dominated. Spain was particularly important for industrial partners. Surprisingly, while many academics engage with partners in China and India, few identified these as key to their project's success. The limited number of hotspots of key academic and industrial partners suggests these countries are both consistently strategically important and academics are able to form relationships with potential partners in these locations. This also suggests that the 'long tail' of other locations are either not strategically important, or are difficult to access, or both.

Why involve international partners?

The study found that involving partners in projects is almost always driven by their research expertise and know-how regardless of where in the world they are based. However, beyond this, partners based in different locations provide access to different types of resources, expertise and competencies to address manufacturing challenges. The workshop discussions and survey also highlighted the importance of established relationships in forming IMRCs. While this inevitably makes it easier to set up collaborations and make them work, this could lead to a degree of path dependence and 'lock-in' that is sub-optimal to producing the best scientific outcomes. Interestingly there was little significant variation in motivations for involving partners from different locations.

Where industry is a major funder of IMRCs, academic partners are more likely to be involved for their commercialisation expertise (in technology transfer) and for insights they have, or can collect, into markets and industry (i.e., market/industry intelligence) than in collaborations funded through other sources. This highlights some of the types of capabilities and knowledge of academics that are valued in major industry-funded projects which are in addition to those valued in solely or largely publicly funded projects. This raises an important question as to whether *and* when these types of capabilities might add value to the latter types of manufacturing research projects.

How do they contribute to innovation?

International manufacturing research collaborations are an important mechanism for advancing the underpinning science and engineering research base, and developing the enabling tools and techniques, for technology-driven R&D. In addition, a range of non-technology based contributions were highlighted. Key amongst these are developing technical, manufacturing and management skills associated with the technical research domains; and contributions to new product development practices and protocols which will likely help to ensure the technical research outputs can be deployed in practice. Less than half of collaborations (around four in ten) anticipate direct contributions to platform technologies, while 29 percent anticipated contributions to specific products and applications. Perhaps surprising was that only 7 percent saw a direct contribution to tool-based services.

Some international manufacturing research collaborations focus primarily on early stages of the innovation process (technology readiness levels (TRLs) 1-2) and make significant contributions to the advancement of the underpinning science and engineering base. However, many projects stretch well beyond these early TRL stages with both industry *and* academic partners involved in activities in the higher stages as well as activities outside the TRL chain that are inevitably important for delivering impacts. IMRCs tend to have a strong focus on science and engineering research and enabling technologies and tools, including the infrastructure (e.g. skills, standards) required to support the diffusion, adoption, and deployment of that technology.

It also suggests that simple analyses of the contributions of research to different technology readiness levels will likely miss the important varieties of technologies supported, and the wider innovation activities necessary to deploy them in the marketplace. This raises an important question about who supports these wider activities and whether this low focus within *international* collaborations is desirable or not for UK value capture. The spanning nature of this research also raises important questions about the efficacy of using the TRL scale in determining the role of the public sector in supporting manufacturing research.

What makes them function effectively?

Making international collaborations work is challenging. Issues relating to human capital, project design, alignment and compatibility, funding and costs, institutional characteristics, and the wider national system, all influence the effective functioning of IMRCs. The study suggested the following:

- **Getting the right people involved is crucial; however, key challenges exist around identifying partners, specific people to involve, and immigration.** A big challenge surrounds how to identify the right individuals and the subsequent difficulties and costs associated with immigration and securing visas for the right to work in, and travel to, the UK. Individuals had to have the right technical skills as well as an interest in collaborating with the UK academics. Given the highly specific nature of research challenges, these individuals are often based outside the UK.
- **Good project management is crucial; however, this was a skill that is underrated in the UK.** In particular it was found to be hard to adequately resource in project proposals. Regular review cycles and reviews of the strategic and technical direction of projects were also seen as important to ensure that they remain on track to deliver valuable outcomes and make mid-course corrections. In addition, collaboration skills, trust, and ability to communicate between partners were viewed as core capabilities necessary to make collaborations work.
- **Collaborations need to deliver benefits to all sides involved.** Effort needs to be invested in ensuring an alignment and understanding of each other's needs and objectives and establishing common objectives. There also needs to be mutuality of credit for delivering outcomes as well as of respect between partners (i.e. partners need to be seen as equals).
- **The funding landscape could be strengthened** to further support international manufacturing research collaborations. Survey respondents highlighted particular challenges around the conditions attached to funding grants, while workshop participants argued that there was a lack of critical mass funding in key areas to enable the UK to take leadership positions in global collaborations which could bring considerable benefits.
- **The support of universities for international collaborations is seen by many as a key enabler although a range of institutional factors can impede their effective functioning.** In particular, the organisation of universities around traditional disciplines makes it much harder to develop collaborations in manufacturing which are inherently interdisciplinary. In

addition, just over a quarter of survey respondents highlighted the formal administrative procedures of their institutions as a significant constraint to making their IMRCs work.

What challenges face partner identification and collaboration setup?

The study also explored the challenges around identifying potential partners and setting up IMRCs. Some of the key issues highlighted include:

- **The ability to identify partners;** a big emphasis is placed on prior professional and personal relationships to identify possible partners. Some seek support from key UK agencies located overseas although their success in identifying partners through this route has been mixed
- **The cost of research in the UK** makes it harder to attract international partners. In addition, the anticipated costs and challenges around immigration and visas can act to prevent collaborations starting in the first place
- **University bureaucracy, administration, and disagreements over intellectual property** can hamper the formation of international collaborations. The disciplinary structure of many universities can make it hard to put in place the necessary multidisciplinary collaborations often required to address manufacturing research challenges. The high turnover of staff in university administration can also create additional challenges and effort to setting up these collaborations as does the lack of a coordination between different administrative functions (e.g. finance, human resources, research contracts etc.)
- **Academic culture and the pressures to publish in high impact journals;** this can disincentivise academics from engaging in international collaborative research and in manufacturing research more widely

What challenges face the exploitation of research outputs in the UK?

It is well known that translating research into commercially viable innovations is a challenging and intrinsically uncertain process. The study identified a wide range of factors that academics involved in IMRCs believe are important for the UK to possess to be able commercially benefit from their research outputs. Key amongst these included the capacity, capability, and willingness of the UK industrial base to absorb, adopt and deploy technologies and processes emerging from UK research. Similarly important was the availability of appropriate factory-like facilities, research and manufacturing skills, and the coordination of public funding.

What should we look out for to ensure an equitable distribution of benefits to the UK?

In a dedicated session, the experts at the workshop made a number of observations about the factors that influence the distribution of benefits between partnering countries. These included:

- The different types of value created (e.g., in products, processes, services), value capture opportunities along the value chain, mechanisms for capturing value (e.g., IP/royalties, contract/in house production, consulting), and ultimate contributions to the national economy (e.g., high value jobs, productivity, tax receipts, company profits)
- Variations in national attributes and infrastructure that influence whether value capture can happen within the UK (e.g. national absorptive capacity, skills, regulations, non-labour costs)

- Requirements for value capture that are intrinsic to the specific research and its application (e.g., the time to deployment, scale of deployment)
- Whether the attributes of the UK firms that might absorb and deploy the outputs from the collaborations are important for national value capture

Participants also identified the importance of how these interact, highlighting their interdependence and how they change over time (their dynamics).

Workshop participants believed all the considerations listed above were essential when attempting to address the question of whether the possible *national* returns from funding a research project are *proportional* to the investment being made in the project compared to the investments being made by, and potential benefits for, *partner nations*.

In conclusion…

The many and varied benefits from collaborating internationally in research are well established. However, this study highlights that making them work requires effort and reveals the range of barriers that need to be overcome and enablers that need to be maintained or enhanced. Crucially, it highlights how the same factor can act as a barrier or an enabler depending on the circumstances. Caution must therefore be used when factors are being scrutinised for their effects on making collaborations work that both the potential positive *and* negative influences are considered.

Involving partners in projects is driven by their research expertise and know-how regardless of where in the world they are based. However, beyond this, partners based in different locations provide access to different types of resources, expertise, and competencies.

UK academics work with key hotspots around the world, citing Germany, France and the US as particularly important locations. Surprisingly few academics viewed China, India and other emerging economies as critical for realising their project objectives. Given the significant growth in scientific, technological and manufacturing capabilities in emerging economies, there may be valuable opportunities for future collaborations with these locations. However, their value should be assessed with respect to the UK's national economic, social and political interests to ensure an equitable distribution of benefits and costs.

IMRCs contribute significantly to advancing scientific understanding. This study revealed that they also contribute to the variety of technologies and wider innovation activities underpinning the development and deployment of an innovation. This suggests that simple analyses of contributions of research to different technology readiness levels may miss the important variety of technologies and wider innovation activities necessary to deploy the core technology.

Furthermore, to enhance the economic and social value capture opportunities for the UK, publicly funded IMRCs would benefit from being scrutinised for the ways in which value can be created, and the necessary combinations of attributes – of the national system, of the technology itself, and of the key industrial actors – required to absorb and deploy the novel innovation.

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1. Introduction

There are many and varied benefits from collaborating internationally in research (Katz and Martin, 1997; Technopolis, 2005; European Commission, 2009; Royal Society, 2011). This report presents the findings of a study that sought to much better understand the landscape of international manufacturing research collaborations (IMRCs) involving UK academics, why UK academics partner internationally, and what makes these collaborations work.

There is renewed interest amongst policymakers in advanced economies around the world on the role of manufacturing in delivering a competitive national economy (Sainsbury, 2007; O'Sullivan, 2011; McKinsey Global Institute, 2012). This is, in part, driven by a growing concern that knowledge-driven economies that lose their production base may lose the ability to innovate in, and capture significant value from, next generation technologies in associated technology spaces (Pisano and Shih, 2009; O'Sullivan, 2011). Related to this, there is growing recognition of the importance of manufacturing research in driving industrial competitiveness, not least in helping industries to address key manufacturing challenges critical to the enabling of next generation technologies and products to be deployed in the marketplace in a commercially viable way (O'Sullivan, 2011).

The study critically looked at *where* UK academics involved in manufacturing research are collaborating with, *why* partners from different locations are brought into the collaborations, *what* types of activities partners from different locations perform in the collaborations, and *what* factors act as barriers or enablers to making them work. It also investigated the anticipated effects of the international manufacturing research collaborations, separating technology-based contributions and wider, non-technology contributions, and the factors may hinder the commercial exploitation of outputs in the UK. Finally, the study examined why some academics choose not to engage in such collaborations.

To address these questions, the report draws on a survey developed as part of the study to explore the above issues. This was distributed to the 1,005 UK academics funded through the Engineering and Physical Sciences Research Council (EPSRC) within their 'Manufacturing the Future' (MtF) research theme. Given the challenges in identifying the manufacturing research community, the principal and co-investigators identified on EPSRC MtF grants provides a valuable starting point for identifying the academic population in this research domain. In total, 164 usable responses were obtained yielding a response rate of 17.3%. In addition, the report draws upon an expert workshop organised by the authors to validate the survey findings around the functioning of IMRCs, and explore the barriers and enablers to building and nurturing them in much more depth and breadth.

Why collaborate internationally?

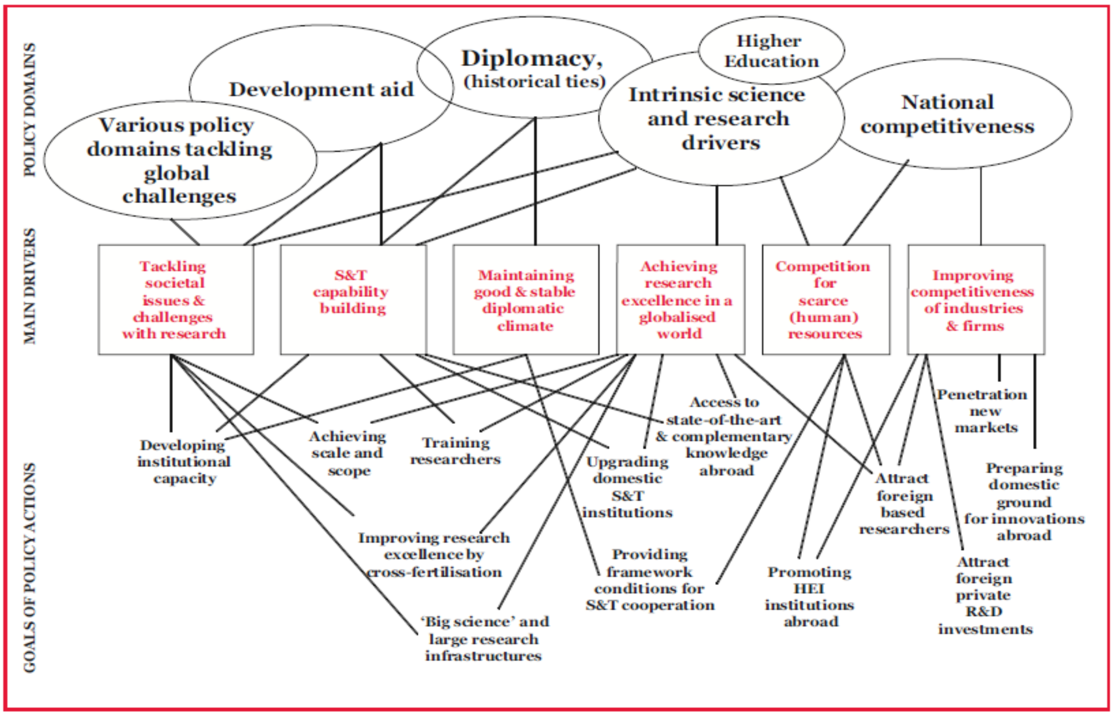
The contributions of science and innovation are well recognised as critical drivers of economic growth in knowledge-driven economies. Reflecting this, many advanced and developing nations have placed science and innovation at the heart of their economic growth and competitiveness strategies.

National science and innovation strategies in most countries acknowledge the importance of international collaborations to achieve their goals (Royal Society, 2011). Indeed, science has long been a cross-border enterprise (Royal Society, 2011). However, pressures to collaborate internationally in research have intensified over the past few decades. Key trends include (Katz and Martin, 1997; European Commission, 2009; Royal Society, 2011):

- The rise of emerging economies – and in particular China – with large research and technological development capacity that meets high international quality standards
- Increasing political debate and urgency of global challenges such as climate change, health issues and sustainable energy resources, all of which benefit from the global collaborative approaches
- Growing need to develop critical mass in research activity
- Partnering with the best researchers globally is increasingly required to remain at the global scientific frontier
- The rising cost of conducting fundamental science at the research frontier making it difficult for individual funding agencies to provide the necessary funding in a particular area
- Globalisation of R&D and the world-wide mobility of researchers
- The importance of social interactions and tacit knowledge transfer in scientific endeavours making formal or informal collaborations necessary
- Increasing need for specialisation within certain scientific fields, especially those incurring high capital costs or with significant scale and complexity where no individual nation will likely be able to perform all necessary tasks to achieve the desired outcomes.
- Increasing shortage of research talent, particularly in science and engineering making it very difficult to find the necessary individuals locally.

Given these trends, collaborating internationally in research is increasingly seen as an imperative and helps to unlock a range of benefits both to the research community and to nation (European Commission, 2009; Technopolis, 2005; Royal Society, 2011; Katz and Martin, 1997). Importantly, the effects are recognised to go beyond science, technology and innovation policy objectives and touch upon a range of other key policy domains (European Commission, 2009) (Figure 1).

FIGURE 1: POLICY DOMAINS, DRIVERS AND GOALS FOR INTERNATIONAL RESEARCH COLLABORATIONS



Source: European Commission (2009, p. 9)

Within the science, technology and innovation policy domain the following benefits have been identified (European Commission, 2009, Technopolis, 2005, Royal Society, 2011):

- Increase the quality of science through researchers seeking the best in the world to work with, cross-fertilization of ideas, and international competition between researchers
- Achieve critical mass and address specific scientific problems that no one nation could pursue effectively and efficiently alone
- Gain access to unique world class expertise, researchers, and industrial clusters that do not exist nationally
- Gain access to a global labour market of research students
- Gain access to specialist overseas or international scientific facilities
- Increase the scope of research (combining complementary knowledge, pooling funding and human resources, sharing risks, increasing computational power)
- Contribute to building institutional capacity in national research organisations
- Gather intelligence on major scientific and industrial breakthroughs internationally
- Develop substantive relationships and/or research capabilities to provide a platform to respond to emerging technological opportunities
- Build consensus internationally on the economic case for major multilateral investments in new or expanded international scientific programmes
- Leverage funding and other financial inducements offered abroad to support the national research endeavour and offset start-up and ongoing costs of international collaborations
- Reduce the financial and other risks in key areas of pre-competitive research requiring substantial investments (e.g. particle physics).

The effects of international collaborations in research within other, non-STI policy areas include:

- Improving national competitiveness:
    - Attracting inward investment (in particular R&D-related investments) and performance of national industries resulting from a strengthening of the attractiveness of the national science and technology system
    - Help local clusters and technology domains build international STI linkages to access best science and technology and develop new business relationships
    - Facilitate access to overseas markets for national companies as part of trade deals
    - Provide national businesses with relevant intelligence and information in key overseas markets
- Tackling global societal challenges such as sustainability, health issues, climate change, biodiversity etc.:
    - The nature and magnitude of major societal challenge require multi-lateral and multi-disciplinary approaches on a global scale and often require large research infrastructures that cannot be easily funded by a single country alone
- Addressing development goals by supporting the development of science, technology and innovation capabilities in less developed countries:
    - Long standing rationale of development policy is to help strengthen scientific and technological capabilities in less developed countries as part of a programme of sustainable development and poverty reduction
- Creating good and stable diplomatic relationships:
    - Foreign relations has long underpinned STI relations, particularly between countries with colonial histories with each other
- Advance higher education policy by promoting a nation's higher education institutions abroad and their internationalisation agendas

The benefits of international collaborations in research have also long been recognised by UK policymakers. For example the value of such collaborations was highlighted in the government's 1993 strategy for science, engineering and technology *Realising Our Potential*: "*Furthermore, certain areas of modern scientific inquiry – such as particle physics and space-based astronomy – require expenditures on a scale that can only be found nationally or even internationally, thereby involving science with diplomacy as well as with domestic politics*" (Realising Our Potential, Cabinet Office, 1993, p.1).

Most recently, the EPSRC strategic plan 2015 explicitly recognises the growing need for the internationalisation of research and cross-border collaborations. It notes: "*[EPSRC] will increase the levels of both multidisciplinary research and international collaboration involving the UK's leading research groups*" (p. 10). The Council is seeking to develop a number of cross-border strategic partnerships with funding agencies abroad to facilitate this process.

Potential Risks and Downsides of International Research Collaborations

Countering the many benefits that are unlocked through collaborating internationally in research are the potential risks and downsides (Office of Technology Assessment, 1995; Katz and Martin, 1997; European Commission, 2002). These include:

- Despite cost to each participating nation may reduce, the overall cost of the research may increase due to increased management and administrative complexity, as well as increased travel and subsistence costs.
- Additional time burdens (and hence costs) can emerge from the increased effort required to international collaborations work, e.g. from preparing joint proposals; developing relationships and overcoming communication and cultural barriers; integrating teams; methods; analyses from different locations; ensuring partners are kept up-to-date with project developments and progress; managing disagreements across different locations etc.
- Transfer of critical, national strategically important, and proprietary knowledge to partner countries enabling them to compete more effectively with the UK, or leakage of such knowledge through partners to unintended (and potentially undesirable) locations
- Create long-term dependencies between partners in particular research and technology domains
- While providing important stability for research projects, organisational and investigative rigidity may emerge to the detriment of the overall research goals
- International collaborations driven by foreign policy or political goals run the risk of producing scientifically inappropriate, ineffective, or politically unstable, projects, to the detriment of science
- Loss of national leadership, prestige and project control in key research domains
- The necessary long-term commitments to projects from all partners can be hard to guarantee
- Distributing costs and benefits equitably between partners can be very challenging

2. Methodology

The report draws primarily on three core sources of evidence developed through the study to inform our understanding of the nature, location and functioning of international manufacturing research collaborations. The first was a database of grants distributed by the Engineering and Physical Sciences Research Council (EPSRC) within their 'Manufacturing the Future' (MtF) research theme. Information was downloaded from the EPSRC Visualising Our Portfolio (VOP) website on 1st July 2015. The second was a bespoke survey developed by the authors and distributed to UK academics involved in manufacturing research. Finally, an expert roundtable workshop was held to explore in more depth the survey findings relating to the initiation and functioning of IMRCs.

Identifying the cohort of academic manufacturing researchers

Manufacturing research is not well defined as a discipline and as such it is hard to identify cohorts of manufacturing researchers through publicly available databases, for example through bibliometric datasets or through grants databases.

To overcome this challenge and identify a population of academics, the study uses the grants distributed through the MtF research theme of the EPSRC. These grants have been deemed by the funding agency to address priority manufacturing challenges. Publicly available grant information not only provide details on the topic of the research and the scale of public funding committed, but also the principal academic investigators and co-investigators involved in the research.

An analysis of the MtF grants database revealed 1,005 unique academics in 69 universities (Table 1). These academics are referred to hereafter as the MtF academic population. The contact details of these academics were identified through publicly available information on university websites. This yielded 951 email addresses. In addition, project partners – largely industrial – are identified in this dataset.

However, grants databases can tell you only so much about the structure and focus of the research and say little on what might affect its exploitation in the UK. They also obviously say little on why academic and industrial partners are brought into the collaborations and the barriers and enablers to making them work. To add value, the study therefore undertakes a survey of the full MtF population to explore these topics.

TABLE 1: DISTRIBUTION OF MANUFACTURING THE FUTURE ACADEMICS BY UNIVERSITY

Rank	University	Number of unique researchers identified
1	Imperial College London	83
2	University of Manchester	62
3	University of Cambridge	60
4	Loughborough University	58
5	University of Nottingham	47
6	University of Sheffield	43
7	University of Bath	41
8	University College London	38
9	Cranfield University	35
10	University of Strathclyde	35
11	University of Bristol	33
12	University of Southampton	33
13	University of Warwick	30
14	University of Birmingham	26
15	Swansea University	23
16	University of Oxford	21
17	University of Leeds	18
18	Brunel University	17
19	Heriot Watt University	17
20	University of Liverpool	17
Top 20 total		737
Total		1005
Share of top 20 in total (%)		73

Source: EPSRC MtF grants database, university websites, authors' analysis

Survey of UK academic manufacturing researchers

A survey was developed for the study to cover the following topics:

- Background information including position and affiliations to different types of organisational entities; prior international experience; and strength of linkages into different academic, industrial and wider stakeholder communities
- Involvement in research projects in the past three years with international collaborators
- Details of a manufacturing research project involving international collaborations including scale and duration; funders and non-financial support; research domains involved
- Geographical location of collaborative partners and identification of up-to-three overseas locations in which most important academic partners are located for realising project objectives and similarly for industrial partners
- Number of academic and industrial partners involved in the project for each of the top three locations, focus of academic/industrial activities in these locations and motivations for involving partners from these locations in the project
- Anticipated effects of the research project outputs distinguishing between technology-based contributions and wider non-technology based contributions; perceived effects on functionality of products/services enabled/enhanced or altered by the research outputs

- Factors affecting potential exploitation of the research project's outputs in UK and current strength of these factors in the UK
- Barriers and enablers for making international collaborations work
- Barriers to setting up international manufacturing research collaborations

The survey was informed by a review of the existing literature on why academics engage in research collaborations internationally and the barriers to making them work. Questions were customised through a series of pilot discussions with researchers operating in this domain to ensure response options were specific to the case of manufacturing research. Insights and comments were also received from the Head of International Innovation Strategy at the Department of Business, Innovation and Skills and incorporated into the questionnaire to ensure that the survey would generate the evidence required by policymakers to inform their funding programmes and decisions.

A pilot version of the survey was distributed by the EPSRC to approximately 100 academics in April 2015. The survey responses as well as feedback on the survey instrument were collected and the survey refined to improve the ease of response and minimise burden on the respondents.

Following the pilot, the survey was distributed to the remaining MtF population in August 2015 with three reminders over the period to December 2015.

The survey yielded 164 usable responses giving a response rate of 17.3% although a number of respondents did not complete all questions. The distribution of the respondents across universities reflects the MtF population well (Table 2).

Table 2: Distribution of the MtF population and survey respondents across universities involved in manufacturing research

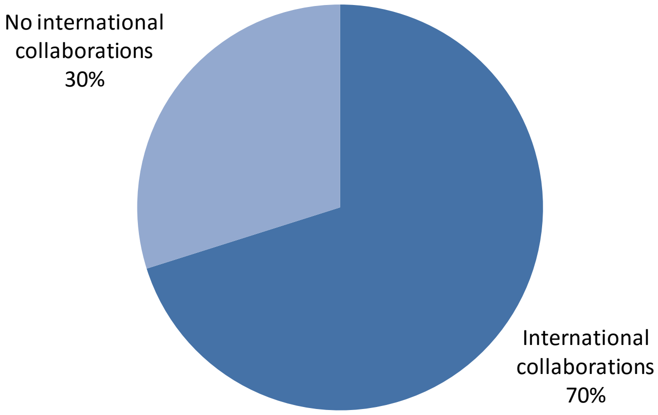
University quartile	Number of universities	Number of researchers		Share of researchers (%)	
		Population	Completed responses	Population	Completed responses
Top quartile	3	205	33	22	20
Quartile 2	6	262	47	28	29
Quartile 3	9	236	45	25	28
Quartile 4	51	247	36	26	22
Missing			3		
Total	69	950	164	100	100

Note: Quartiles determined by the number of academics by university involved in the EPSRC MtF portfolio. The groups are uneven due to universities at the borders between quartiles being allocated to a particular group.

Sources: EPSRC Visualising Our Portfolio MtF research theme; IMRC survey, authors' analysis

The survey revealed that 70% had engaged in a project over the past three years involving an international partner (Figure 2).

FIGURE 2: SHARE OF SURVEY RESPONDENTS WITH INTERNATIONAL COLLABORATIONS IN MANUFACTURING RESEARCH



Source: CSTI survey of manufacturing researchers 2014, authors' analysis

Expert workshop on building and nurturing effective international manufacturing research collaborations

The final source of evidence was an expert workshop on building effective international manufacturing research collaborations. The workshop aimed to explore in much more breadth and depth the particular barriers and enablers that influenced the initiation and functioning of IMRCS. It sought to both test the robustness of the survey findings in this area and provide an opportunity to expand the richness of our understanding of these factors. In addition, the workshop explored what factors might swing the expected benefits from collaborations too far away from the UK leading to a significantly unbalanced partnership.

The workshop involved nine researchers, mostly from the sample of attendees from the survey respondents and was held in London on 9th March 2016. They covered a range of sub-domains of manufacturing research. In addition, officials from BIS and the EPSRC were also in attendance providing valuable policy perspectives to the discussions.

Critically, while the workshop was largely about better understanding the factors that influence the setting up and functioning of IMRCs with little structured discussion on their value, workshop participants were very keen to point out that we should not lose sight of the significant benefits derived from these projects to both the UK research community and UK plc more widely. They were seen as crucial for maintaining the UK at the forefront of the scientific endeavour in manufacturing (and related) research.

3. About manufacturing research in the UK

Key points from this section

Manufacturing research…

- …focuses on addressing needs and issues related to the manufacture of new and existing products, and with attention to efficiency, sustainability, and the economics of production (frequently focusing on new product development and deployment).
- …encompasses theories & methods for the definition, synthesis, analysis and simulation of engineered products, processes and services
- …expands to consider more than just the firm-level manufacturing system including the supply, distribution and support network for the engineered products, processes and services
- …is key to enabling technology-based concepts emerging from basic research to be scaled-up, and commercially deployed in the marketplace and deliver economic and social impacts

Our analysis highlights

- Manufacturing research covers a broad range of sub-domains including manufacturing technologies; materials engineering; chemical engineering; and optics, photonics and electronics engineering.
- Most manufacturing researchers are affiliated to a departmentally based research centre or group and many are also affiliated to wider multi-disciplinary centres and institutes
- Most manufacturing researchers have prior experiences working or living abroad, in particular in the US, Germany, France, China and Italy

Before diving into the landscape of international manufacturing research collaborations, their anticipated impacts and what makes them work, it is important to understand the nature of manufacturing research, as it is a broad and complex landscape and its boundaries are poorly understood. This section examines how the community of manufacturing researchers defines manufacturing research, and explores the scale of activity in the UK and some characteristics of those involved in this type of research. To do so, we draw upon information provided in the grants database of the EPSRC Manufacturing the Future research portfolio as well as some base information provided by the survey respondents.

What is manufacturing research: views of the community

The manufacturing research community that responded to the survey were provided the opportunity to offer their own definition of manufacturing research. The following statements highlight the variety of responses received.

Manufacturing research:

- … encompasses theories & methods for the definition, synthesis, analysis and simulation of engineered products, processes and services; and networks of organisations that realise, deliver, and support these products, processes and services to users
- … contributes to any point along the product lifecycle with particular emphasis on manufacturing phase
- … includes basic or applied research in physical/chemical sciences where the design of the research has to consider the implications for future manufacture and make early-stage choices accordingly
- … covers any technical aspect of manufacturing (i.e. not management or legal research)
- … research into making things
- … encompasses fundamental and applied device development, as well as production processes to make possible new technologies, or improve efficiency or sustainability of existing production runs
- … enables the transition from basic science to full-scale commercial production
- … advances understanding of the mechanisms and methods of realising transformational processes

These statements emphasise the following characteristics of manufacturing research:

- It focuses on addressing needs and issues related to the manufacture of new and existing products, and with attention to efficiency, sustainability, and the economics of production (frequently focusing on new product development and deployment).
- It encompasses theories & methods for the definition, synthesis, analysis and simulation of engineered products, processes and services
- It expands to consider more than just the firm-level manufacturing system including the supply, distribution and support network for the engineered products, processes and services
- Manufacturing research is key to enabling technology-based concepts emerging from basic research to be scaled-up, and commercially deployed in the marketplace and deliver economic and social impacts

Scale and focus of academic manufacturing research funded by the EPSRC

The EPSRC MtF portfolio listed 385 projects with £517.1 million allocated from 2009 to 2023 (£282.5 million between 2009 and 2015).

These projects covered a range of research sub-domains (Table 3). The vast majority of these grants (almost 60%) are identified within the 'manufacturing technologies' research domain of the EPSRC with the remaining grants are spread across a variety of other domains including materials engineering, chemical engineering, engineering design, bio-engineering, and optics, photonics and electronics engineering.

There was also a significant degree of variation by research sub-domain in the degree of inter-institutional collaboration on grants both in terms of the number of different universities listed and the number of project partners (typically firms) engaged (Table 3). For example, engineering design grants on average had the fewest project partners (1.8 per grant) while those in optics, photonics and electronics engineering had the most (5.5 per grant). In terms of inter-university collaboration, grants with a primary focus on chemical engineering listed the highest number of different institutions (6.7 per grant), followed by engineering efficiency (6.1 per grant) while grants in intelligent systems and reality-virtual interface and mechanical and civil engineering had the fewest (1.4 per grant and 1.7 per grant respectively).

There was also significant variation in the average value of grants distributed. Those with a primary focus on optics, photonics and electronics engineering received on average the most (£2.6 million per grant) followed by those in engineering efficiency (£2 million per grant), while those focusing on engineering design received the least (£0.6 million per grant).

TABLE 3: CHARACTERISTICS OF GRANTS BY KEY EPSRC RESEARCH DOMAINS OF THE MANUFACTURING THE FUTURE PORTFOLIO

Primary research area	Number of grants	Total value of grants (£mill)	Average grant value (£mill)	Average number of project partners per grant	Average number of academics per grant	Average number of universities involved per grant
Manufacturing technology	228	290	1.3	4.1	3.4	3.1
Materials engineering	32	47	1.5	2.4	3.4	2.5
Chemical engineering	21	40	1.9	4.4	5.5	6.7
Engineering design	21	12	0.6	1.8	3.0	2.6
Bio-engineering	17	19	1.1	2.6	3.3	2.2
Optics, photonics & electronics engineering	17	44	2.6	5.5	4.5	5.0
Mechanical & civil engineering	9	14	1.6	4.1	3.0	1.7
Engineering efficiency	8	16	2.0	5.3	5.5	6.1
Intelligent systems and reality-virtual interface	7	6	0.9	4.1	2.0	1.4
Control Engineering	3	4	1.3	4.0	5.7	4.7
Other	19	23	1.2	5.8	3.7	3.2
All	385	517	1.3	4.0	3.6	3.3

Source: EPSRC MtF grants database, authors' analysis

Manufacturing researcher affiliations

The survey of university-based manufacturing researchers examined their institutional affiliations. It revealed that most researchers are linked to a department-based research centre or group and almost a third are affiliated with wider multi-disciplinary university-based research centres and institutes. Just over a quarter of respondents to the survey were affiliated to the EPSRC's Centres for Innovative Manufacturing and just under a quarter had links with Innovate UK's Knowledge Transfer Networks.

TABLE 4: AFFILIATIONS OF SURVEY RESPONDENTS TO DIFFERENT ORGANISATIONAL ENTITIES IN THE RESEARCH BASE

Affiliations	Total	International collaborations involved (% respondents)	
		Yes	No
Department based centre/research group/research lab	89.0	90.4	85.7
Other wider multi-disciplinary university research centre/ institute	32.3	35.7	24.5
Centre for Innovative Manufacturing	26.2	29.6	18.4
Knowledge Transfer Network (KTN)	23.2	27.0	14.3
Other cross-institutional partnering entity	14.0	16.5	8.2
Other	14.0	13.0	16.3
None of the above	4.9	3.5	8.2
Affiliation counter	164.0	115.0	49.0

Source: CSTI survey of manufacturing researchers 2015

Embeddedness of academics in key stakeholder networks

Many of the manufacturing researchers who responded to the survey were also strongly linked into key stakeholder communities. Almost 70% claimed to have strong links with key players in industrial firms relevant to their research projects and 81% were strongly linked into the wider academic research community in the area of their research project. However, links into government departments and agencies were much weaker, with just 12% claiming to have strong links with key players. A similar pattern existed with standards setting bodies.

TABLE 5: STRENGTH OF LINKAGES OF SURVEY RESPONDENTS INTO KEY COMMUNITIES

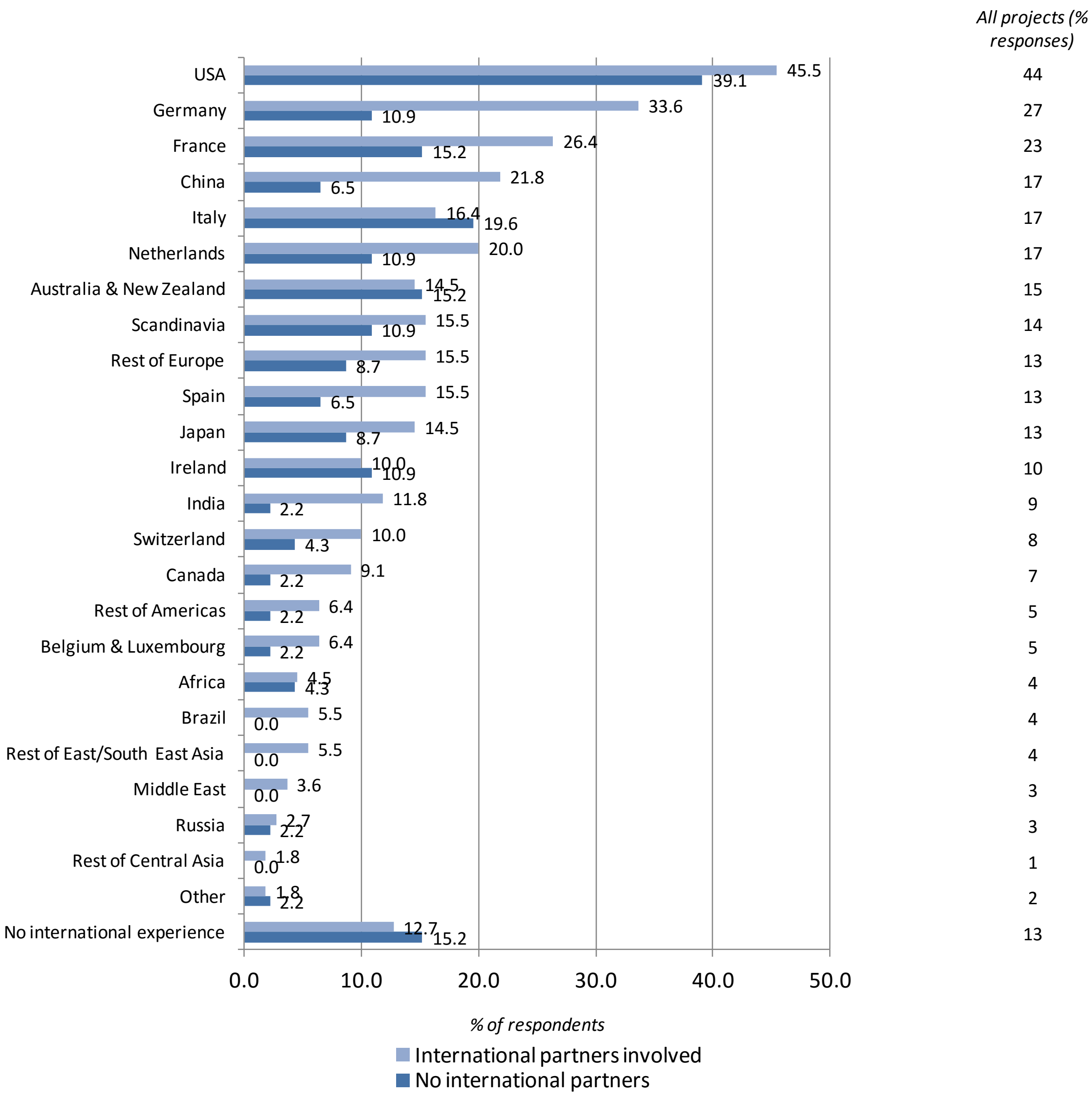
	Academics with international collaborations (% respondents):			
	None	Few links with non-core players	Weakly linked with key players	Strongly linked to key players
Industrial firms relevant to this research project	3	3	25	69
Other industrial firms relevant to the wider research domain	6	9	31	50
Academics/other researchers in the research domain relevant to this project	0	4	15	81
Academics/other researchers in other research domains	1	8	40	47
Policymakers & government agencies in areas relevant to the application of your research	20	32	32	12
Standards setting bodies	36	25	24	11
Other organisations e.g. trade associations / NGOs / UN / World Bank (please specify):	57	13	11	5
Linkage Counter	114	114	114	114

Source: CSTI survey of manufacturing researchers 2015

Prior international experience

The focus of this study is on international manufacturing research collaborations involving UK academic researchers. The survey highlighted that most individuals in this community had some prior exposure internationally either through work, education or residence in a particular location (Figure 3). Forty-four percent had prior experience in the USA, 27% have had prior experience in Germany and 23% in France. Seventeen percent of the sample had some prior experience in China while just 9% had some experience in India. However, there was significant variation between IMRCs and those projects with no international experience. For example while academics in both types of projects had prior experiences in the US and Italy, big disparities emerge for other countries. Academics in IMRCs are much more likely than other projects to have had prior experiences in other countries such as Germany, China, France, Spain and India.

Figure 3: Prior experience of survey respondents



Number of responses: Projects with international partners: 110; no international partners: 46
Source: CSTI survey of manufacturing researchers 2015

4. Characterising international manufacturing research collaborations

Key points from this section

- International manufacturing research collaborations vary in scale (based on cost), the number of partners involved and the balance between academic and industrial partners
- The average annual cost of these international collaborations in this research domain was £1.1 million with an average duration of 3 years
- Most international manufacturing research collaborations encompass some research in applied science and technology, while many also involve production engineering and decision systems engineering (in particular sensors). Some projects also stretch beyond these areas to include issues of management, innovation systems, policy and skills as applied to manufacturing challenges
- Key sources of funding for academic international manufacturing research collaborations were the EPSRC, the European Union funding programmes and industry

The report now turns to more fully characterising the scale, structure and focus of international manufacturing research collaborations in which UK academics are involved.

Scale of international manufacturing research collaborations

The average annual financial cost of the projects identified in the survey was £739,000 (Table 6). However, international manufacturing research collaborations (IMRCs) on average cost more per year (£1.14 million) and lasted longer (on average 3 years) than projects not involving international partners (£346,000 per year, lasting 1.9 years). The increased cost will likely in part reflect a higher number of partners involved.

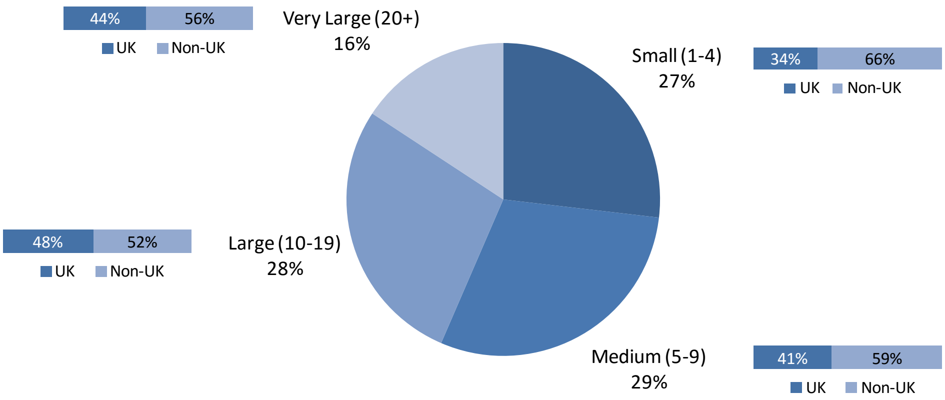
Table 6: Average financial costs of projects

	Total	International collaborations involved	
		No	Yes
Average financial cost (£000s)	3,004	1,401	3,680
Average annual financial cost (£000s)	739	346	1,136
Average duration (years)	2.7	1.9	3.0
Number of responses	134	26	108

Source: CSTI survey of manufacturing researchers 2015

International manufacturing research collaborations also exhibited considerable variation in the number of academic and industrial partners involved in the projects (Figure 4) with 27% of projects involving 1-4 partners; 29% involving 5-9 partners; 28% involving 10-19 partners and 16% involving over 20. In a very few cases, projects involved more than 40 partners. Figure 4 also highlights that small projects are much more likely than others to have a larger share of project partners overseas.

FIGURE 4: NUMBER OF PROJECT PARTNERS INVOLVED (% OF TOTAL IMRC PROJECTS) AND PROPORTION OF PARTNERS OVERSEAS FOR EACH GROUP (% OF GROUP TOTAL)



Source: CSTI survey of manufacturing researchers 2015

Partner composition of international manufacturing research collaborations

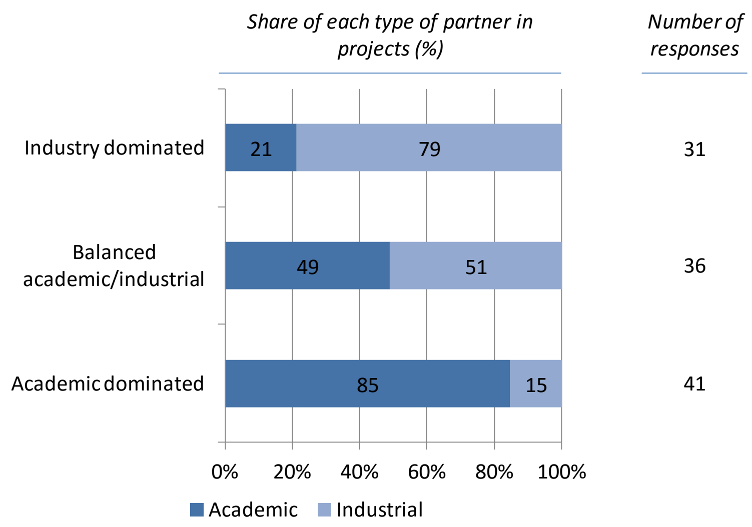
The survey also reveals quite different partner compositions – in terms of the balance of academic and industrial partners – within IMRCs. There is a wealth of evidence highlighting the differences between universities and firms in terms of the functions they perform within the innovation system, their motivations and orientations as organisations, and the cultures that influence the activities of their employees. These differences create additional challenges for operating collaboratively compared to collaborations between similar types of organisations.

We segmented the survey sample into three categories based on the following criteria:

- Academic dominated: number of academic partners more than twice the number of industrial partners
    - On average 85% of project partners were academic while 15% were industrial (Figure 5)
- Industry dominated: number of industrial partners more than twice the number of academic partners
    - On average 21% of project partners were academic while 79% were industrial (Figure 5)
- Balanced: number of academic (industrial) partners less than twice number of industrial (academic) partners
    - On average 49% of project partners were academic while 51% were industrial (Figure 5)

This partner composition definition is used throughout the report to explore different types of international manufacturing research collaborations.

FIGURE 5: COMPOSITION OF ACADEMIC AND INDUSTRIAL COLLABORATORS



Source: CSTI survey of manufacturing researchers 2015

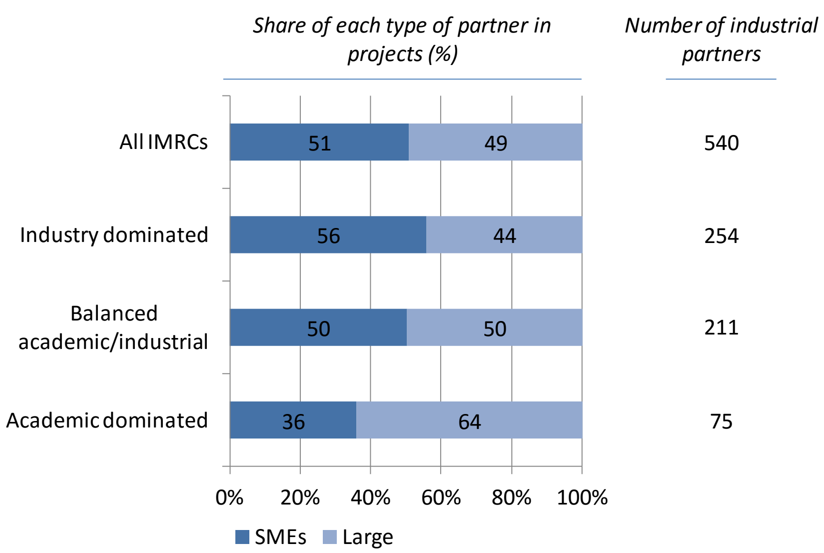
Despite IMRCS having quite different partner compositions, the average number of project partners for these subgroups was remarkably similar (Table 7).

TABLE 7: NUMBER OF ACADEMIC AND INDUSTRIAL PARTNERS INVOLVED

	Average number of partners	Average number of academic partners	Average number of industrial partners
Academic dominated	11.9	10.1	1.8
Balanced	11.5	5.6	5.9
Industry dominated	10.6	2.3	8.3
All IMRCs	11.4	6.4	5.0

Source: CSTI survey of manufacturing researchers 2015

FIGURE 6: COMPOSITION OF ACADEMIC AND INDUSTRIAL COLLABORATORS



Source: CSTI survey of manufacturing researchers 2015

Turning to the types of industrial partners involved (Figure 6), it is clear that while the average for all projects suggests a relatively even balance between small and medium sized enterprises (SMEs) and large companies, there is considerable variation between the subgroups. While academic dominated projects are likely to have more large companies involved than SMEs, the reverse is typical for industry-dominated projects.

Research domains of international manufacturing research projects

The projects identified by the survey cohort were also characterised based on the research sub-domains they focused on. The study adopted the manufacturing research sub-domains identified in O'Sullivan (2011) which, in-line with the definitions highlighted by the community in the survey, takes a broad view of the research domain. It identifies the following broad categories:

- Management, innovation systems & policy applied to manufacturing challenges
- Decision system engineering applied to manufacturing industries
- Physical production engineering
- Applied science & technology

Table 8 highlights how engagement across these four core categories varies between those projects with and without international partners and, for those with IMRCs, variations between different partner compositions. Most projects involve some degree of applied science and technology. This is perhaps unsurprising given that the cohort of researchers from which the survey drew its sample was the EPSRC's manufacturing the future portfolio. As a primary funder of university-based manufacturing research in the UK, the EPSRC typically funds research at the more fundamental end of the research spectrum and focuses on research in engineering and physical sciences domains.

Table 8: Research domain groups of the projects involving international manufacturing research collaborations (% respondents)

Project research domain group	Total	International partners		Partner composition (IMRCs only)		
		No	Yes	Academic dominated	Balanced	Industry dominated
Mgt, Innov Syst, & Policy	20	14	21	17	17	32
Decision Syst Eng	42	57	38	29	42	45
Production Eng	64	57	65	63	72	61
Applied S&T	80	64	84	88	89	71
Other	14	25	12	10	17	10
Number of respondents	141	28	113	41	36	31

Source: CSTI survey of manufacturing researchers 2015

Examining the differences between IMRCs and those projects without international partners, the survey suggests that the former are more likely to include activity in applied science and technology, while the latter are more likely to focus on activity in decision system engineering areas.

The survey also suggests that industry-dominated IMRCs are more likely than academic dominated IMRCs to be undertaking research in the areas of management, innovation systems & policy (as applied to manufacturing challenges). In addition they are more likely to focus on decision system engineering. However, they are relatively less likely than other types of IMRCs to involve applied science and technology in the project although this is still a major focus for many of these types of collaboration.

Table 9: Detailed research domains of the projects involving international manufacturing research collaborations (% respondents)

Research domain		All IMRCs	For international collaborations: partner composition groups			Sig. [a]
			Academic dominated	Balanced	Industry dominated	
Management, innovation systems & policy applied to manufacturing challenges	Innovation systems	13	12	8	19	
	Industrial economics	12	7	8	19	
	Service enterprise systems	4	0	6	3	
	Industrial policy	3	0	3	3	
	Organisation analysis	7	5	3	13	
Decision system engineering applied to manufacturing industries	Sensors and sensing systems	23	20	22	29	
	System design & simulation engineering	13	10	11	16	
	Reconfigurable manufacturing systems	12	5	14	19	
	Control systems	8	5	8	10	
	Visualising & virtual prototyping systems	4	5	3	3	
	Operations systems research	6	5	6	6	
	Product-service systems	6	0	8	10	†
	Logistics & distribution	2	0	0	3	
	Industrial organisational systems	3	0	3	3	
Physical production engineering	Materials process & performance control	43	41	47	42	
	Fabrication & processing technology	43	39	47	48	
	Manufacturing machines & equipment	23	24	28	16	
	Advanced processing & packaging	34	24	44	32	
	Production scale-up (emerging industries)	21	17	31	16	
Applied science & technology	Materials science	68	71	75	52	*
	Device physics	23	22	25	23	
	Biotechnology	17	24	19	3	**
	Applied chemistry	24	15	25	39	*
Other	Other (please specify):	12	10	17	10	
Number of respondents		113	41	36	31	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level
Source: CSTI survey of manufacturing researchers 2015

Table 9 provides a much more granular analysis of the sub-domains involved in IMRCs and the breakdown by different partner compositions. It reveals that much of the activity in applied science and technology focuses on materials science and, for industry dominated projects on applied chemistry. Academic dominated and balanced projects are much more likely than their industry-dominated counterparts to focus on biotechnology. Much of the activity in the physical production engineering category focuses on addressing issues around materials process and performance control, and fabrication and processing technology, while that in decision systems engineering centres on sensors and sensing systems.

Funders of international manufacturing research collaborations

Different funding sources for academic research can have quite different conditions attached to them. Understanding the variety of sources for IMRCs is therefore important. The survey explored the sources of significant funding for projects, defined as providing more than 25% of the project value. Projects could thus identify more than one source.

The survey suggests that manufacturing research academics drew from a variety of sources to support their research collaborations, in particular the EPSRC (39% of academics), EU framework programmes (32%) and industry (18%) (Table 10). Interestingly, 12% of academic-dominated projects had significant sources of industry funding compared with just under a quarter for industry-dominated projects. While industry is perhaps unsurprisingly a significant source of funds for projects with a large proportion of industrial partners in comparison with academic partners, they are also involved as major funders in projects where the reverse is true. Big variations emerge, however, when one breaks the sample down by different types of projects. Firstly, the UK only projects are much more likely than IMRCs to have EPSRC as a significant funder, while EU framework programmes (by definition) are a key source of funding for IMRCs. In addition, those projects with a balanced partner composition were much more likely to be funded by the EU framework programmes.

Table 10: Manufacturing research collaboration funding sources for different types of project (% respondents)

Primary funder (more than 25% of value)	Total	International collaborations involved		For international collaborations: partner composition groups		
		No	Yes	Academic dominated	Balanced	Industry dominated
EPSRC	39	29	78	29	23	40
EU Framework Programmes	32	40	0	32	51	37
Industry	18	18	19	12	14	23
Non-UK governments	9	12	0	15	6	10
BIS/Innovate UK/HEFCE/Other UK govt agencies	9	8	11	12	9	3
Other EU	7	7	7	5	9	7
Other UK Research Councils	4	4	4	7	6	0
Other funding sources	11	13	4	22	6	7
Number of responses	140	27	113	41	35	30

Source: CSTI survey of manufacturing researchers 2015

An analysis of the major and minor funding sources for IMRCs also provides a useful categorisation of projects based on the balance of public-private sector funding received (Table 11).

Table 11: Funding sources for projects international manufacturing research collaboration projects categorised by funding type (% respondents)

Funding source	Major source of funding (more than 25% of value)				Minor source of funding (less than 25% of value)			
	Public funded	Minor industry	Major industry	Other	Public funded	Minor industry	Major industry	Other
EPSRC	15	59	40	32	2	6	5	5
EU Framework Programmes	65	35	10	9	2	0	5	5
Industry	0	0	100	0	0	100	15	9
Non-UK governments	2	6	0	50	2	18	5	5
BIS/Innovate UK/HEFCE/Other UK govt agencies	6	0	10	18	2	12	10	5
Other EU	9	0	15	0	0	12	0	0
Other UK Research Councils	4	0	0	14	0	12	0	0
Other funding sources	0	0	15	55	2	47	10	0
Number of respondents	54	17	20	22	54	17	20	22

Source: CSTI survey of manufacturing researchers 2015

The following categories were created:

- Public funding: mostly funded through UK and/or European Union public sector funding programmes with no industry funding (largely EU framework programmes and some EPSRC)
- Minor industry: Public sources of funding (largely EPSRC and EU framework programmes) are the major source of finance, with industry contributions less than 25% of project value
- Major industry: Projects where industry funding is a major source of finance, often alongside public funding from the EPSRC or other government agencies
- Other: Projects with where industry is not a major funder and involve funding from other sources (including non-EU government funders, charities and trusts, internal funding from UK or overseas universities)

Non-financial support for building international manufacturing research collaborations

In addition to financial support, 24% of respondents indicated that they had received non-financial support from funders to help them develop their international manufacturing research collaborations. Support included:

- Support for workshops (including bringing together the different academic, industry and regulatory stakeholders associated with the planned research) and partnering events
- Help in identifying project partners, including facilitating access to company supply chains
- Support for project monitoring and evaluation, including setting targets and individuals to act as project assessors and monitors
- Access to facilities
- Support for secondments from industry, knowledge exchange posts and administration
- Seminars and support related to exploitation and commercialisation
- Project management and conflict mediation support
- Web support

5. Locations of international partners in manufacturing research

Key points from this section

- The survey highlights the importance of Germany, France and the US as key locations for academic and industrial partners in manufacturing research.
- Spain and Italy are frequently cited as important industrial partner locations but less so as locations for academic partners.
- While many respondents identified China, Australia & New Zealand, Ireland, Switzerland and Japan as places where they partner with, these locations are rarely seen as critical for realising project objectives.
- Project partner locations do not correlate strongly with patterns of co-authorship in scholarly publications.

This section explores the geographic footprint of international manufacturing research collaborations involving UK academics. It provides the baseline for exploring in later sections the degree of specialisation of labour between the UK and other nations and why UK academics are choosing to interact with these locations.

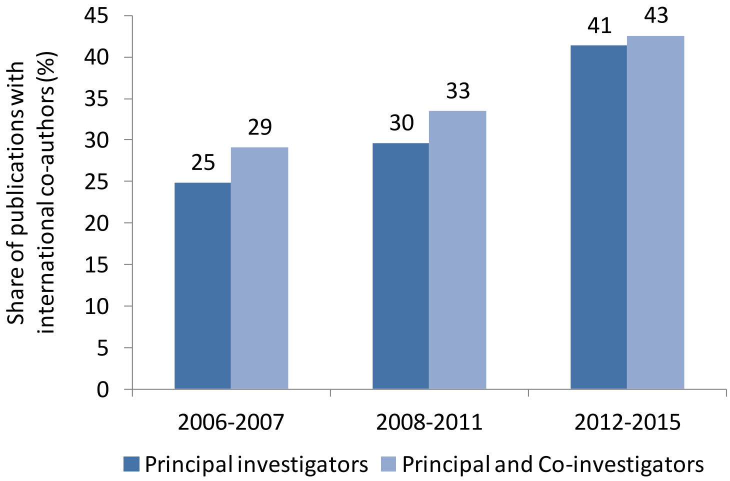
The section draws on two primary sources of evidence. The first is the geographic footprint of co-authored scholarly publications involving the principal investigators funded under the EPSRC's Manufacturing the Future portfolio. The second is the evidence generated in the survey of UK manufacturing researchers which identifies the locations of academic and industrial project partners.

Geographic footprint of *co-authored publications* by UK manufacturing researchers

The EPSRC's manufacturing the future portfolio identified 1,005 unique academics, of which 276 were identified as principal investigators (PIs). Searching for the names of these individuals in Thomson Reuters Web of Science database of scholarly publications identified 19,565 publications between 2006 and 2015 (5,756 for PIs only).

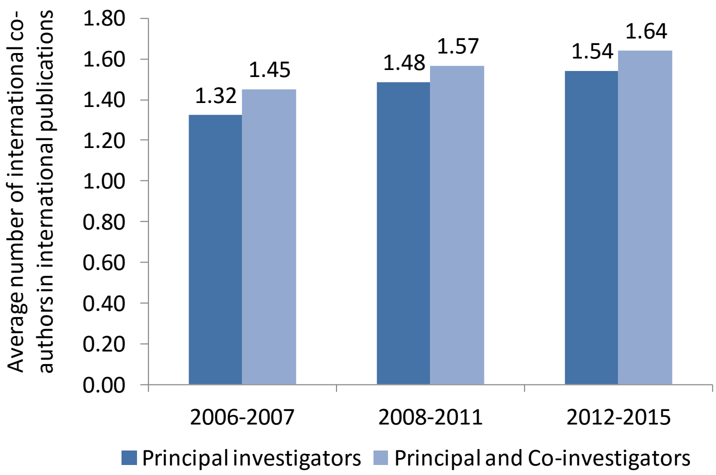
Figure 7 reveals that a growing proportion of publications emerging from this cohort of academics involve international co-authors, with just over 40% doing so in 2012-15. This is up from just over 30% in 2008-11. In addition, the average number of co-authors in internationally co-authored publications is increasing over time amongst this cohort of academics (Figure 8).

FIGURE 7: SHARE OF PUBLICATIONS INVOLVING UK ACADEMICS WITH INTERNATIONAL CO-AUTHORS



Source: CSTI survey of manufacturing researchers 2015

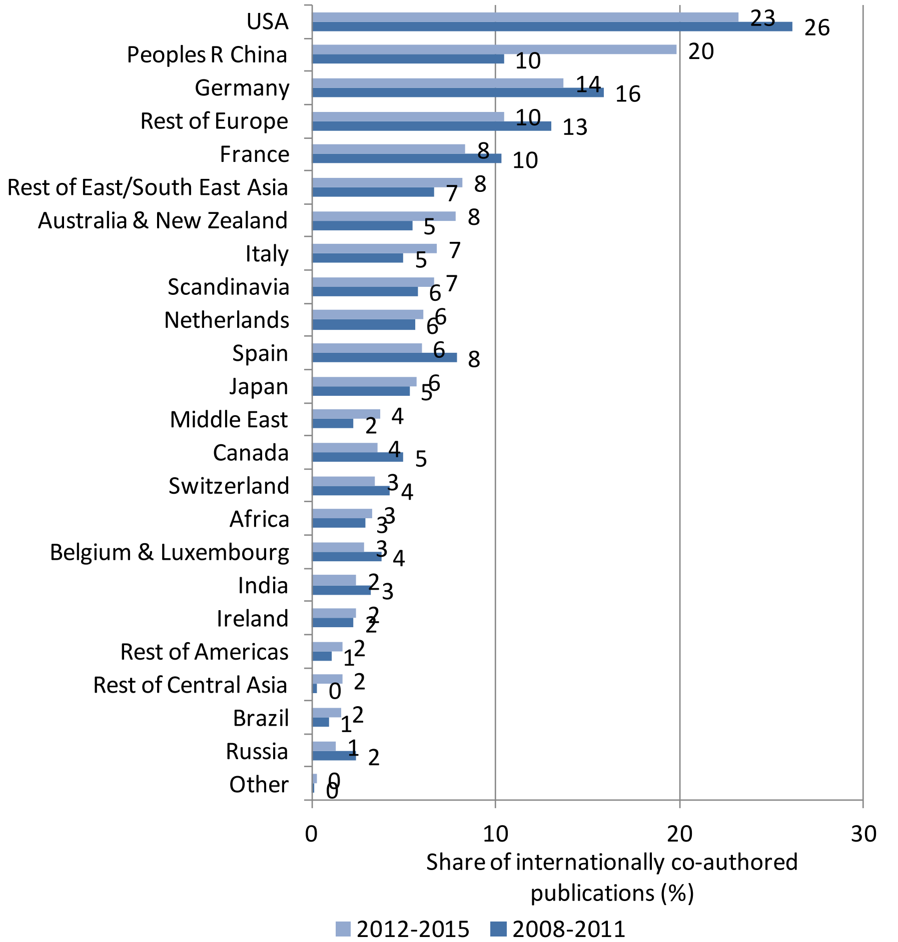
FIGURE 8: AVERAGE NUMBER OF INTERNATIONAL CO-AUTHORS FOR INTERNATIONALLY CO-AUTHORED PUBLICATIONS INVOLVING UK ACADEMICS



Source: CSTI survey of manufacturing researchers 2015

The range of countries engaged by the PIs of the EPSRC's MtF portfolio in 2008-11 and 2012-15 is shown in Figure 9. Just under a quarter of internationally co-authored publications by these PIs involve co-authors in the US between 2012-15, although this has fallen from 26% in 2008-11. The next biggest partner for publications in 2012-15 is China with 20% of publications involving a China-based co-author. This has jumped from just 10% in 2008-11, the largest jump for any location. Germany, Rest of Europe and France are also frequent locations for co-authors for the manufacturing PIs. Publications involving co-authors from Australia and New Zealand have seen a significant rise between periods from 5% to 8%.

FIGURE 9: COUNTRIES INVOLVED IN INTERNATIONALLY CO-AUTHORED PUBLICATIONS INVOLVING UK ACADEMICS



Number of internationally co-authored publications by UK EPSRC Manufacturing the Future principal investigators: 2008-11: 662; 2012-15: 1,160

Source: CSTI survey of manufacturing researchers 2015

Geographic footprint of international *project partners* of UK manufacturing researchers

The geographic footprint of co-authorship of scholarly publications provides only partial insights into the global academic and industrial networks within which UK academics find themselves. For example, publications are but one type output of academic research. In addition, it will likely bias against industrial partners who may not be interested or willing, or have the bandwidth, to contribute to publications. Given the nature of manufacturing research where outputs typically stretch well beyond scholarly publications and into proprietary products, processes and know-how, these limitations are likely to be particularly severe.

The survey of manufacturing researchers therefore sought to identify the number and location of academic and industrial partners involved in undertaking activities within the project. The survey also identified those locations that were considered to be most important for realising the project's objectives. The locations for any academic and industrial partners and the top partner locations are shown in Table 12.

TABLE 12: INTERNATIONAL MANUFACTURING RESEARCH COLLABORATIONS BY COUNTRIES/REGIONS (% RESPONDENTS)

Country/region	Any partner in locations:		Top 3 partner locations:		Sig.[a]
	Academic partners (%)	Industrial partners (%)	Top academic partners (%)	Top industrial partners (%)	
Germany	51	42	47	33	*
France	38	21	21	16	
USA	33	23	29	19	*
Italy	31	23	9	19	*
Scandinavia	28	18	18	11	
Netherlands	27	23	15	15	
Spain	26	19	11	22	**
China	25	10	7	4	
Rest of Europe	24	15	21	11	
Australia & New Zealand	20	5	6	0	**
Ireland	18	9	8	2	**
Switzerland	16	10	6	5	
Japan	15	11	8	5	
Belgium & Luxembourg	15	17	8	8	
India	14	6	7	2	†
Canada	10	5	5	3	
Rest of East/South East Asia	6	6	7	3	
Brazil	6	6	2	1	
Russia	5	2	2	1	
Middle East	4	3	1	3	
Rest of Americas	4	2	1	0	
Africa	3	3	1	0	
Rest of Central Asia	1	1	0	0	
None (if completed table)	5	9	n/a	n/a	
Number of respondents	96	96	107	96	

Note: results in the first set of columns exclude responses from the pilot survey due to slight modification of the question between the pilot and main phases

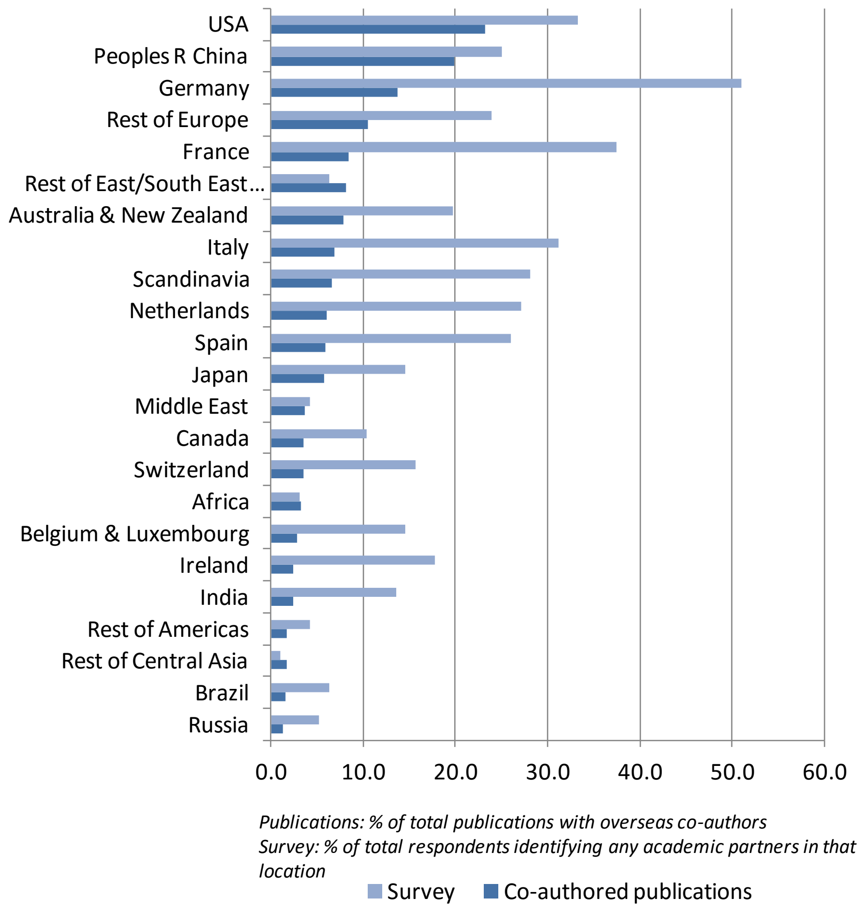
[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level
Source: CSTI survey of manufacturing researchers 2015

Table 12 highlights the importance of Germany as a core academic and industrial partner for enabling UK academics engaged in manufacturing research to realise their project objectives. Almost half of respondents identified it as a top academic location with a third identifying important German-based industry partners. The US is similarly an important top academic and industrial partner location for realising project objectives as is France. Italy and Spain are more frequently cited as important industrial partner locations than as academic partner locations.

Interestingly, while a quarter of respondents identified academic partners in China and 10% of respondents identified industrial partners there, very few saw this location as core for realising their project objectives. The same was true for India, Japan, and Australia & New Zealand, and a number of European locations including Ireland and Switzerland.

The survey responses also highlight the importance of moving beyond publications to examine partner location. Figure 10 compares the locations identified in the analysis of internationally co-authored publications by the cohort of UK manufacturing researchers funded by the EPSRC (although they were able to identify and respond based on projects funded by other organisations including the European Union) and those identified in the survey of a sample of this cohort. Striking differences emerge. In particular the US emerges as a much more important academic project partner than would be suggested by an analysis of publications as do Germany, France and many of the European nations. Similarly India emerges as more important as does Australia & New Zealand.

FIGURE 10: COMPARING ACADEMIC PARTNER LOCATIONS USING PUBLICATIONS AND SURVEY RESPONSES



Source: CSTI survey of manufacturing researchers 2015

Table 13 shows how the geographic reach of projects with different funding sources varies. It is clear that projects with significant EU funding largely involve European partners. Research Council projects (largely EPSRC funded) involve partners in various European nations (particularly Germany and Spain) as well as the US (35% of projects with this funding), Japan, India and Canada. Projects with significant industry funding frequently engage US, German, Belgian/Luxembourg and French partners as well as organisations in Japan, China and the rest of East/South East Asia.

TABLE 13: GEOGRAPHIC DISTRIBUTION OF PROJECTS WITH DIFFERENT TYPES OF FUNDING

Country/region	Source of funding (% of total for each source)			
	Research council funded	EU funded	Industry	Other
Germany	28	69	24	11
France	10	33	20	17
Italy	8	31	0	6
Netherlands	8	29	8	0
Belgium & Luxembourg	8	11	24	0
Switzerland	3	15	0	0
Ireland	3	11	0	11
Spain	15	27	16	0
Scandinavia	7	29	12	6
Rest of Europe	8	33	4	11
USA	35	4	44	33
Canada	8	2	4	0
Brazil	0	2	0	6
Australia & New Zealand	5	0	4	17
Japan	10	0	16	22
China	5	5	12	11
India	8	0	4	6
Russia	0	2	0	6
Africa	0	0	0	6
Middle East	2	5	0	0
Rest of East/South East Asia	0	5	16	11
Rest of Central Asia	0	0	0	0
Rest of Americas	0	2	0	0
Number of respondents	60	55	25	18

Source: CSTI survey of manufacturing researchers 2015

There are also differences in top partner locations for different sized projects (categorised by financial cost). Large projects are much more likely than small projects to cite Germany as a key partner for both academic and industrial projects, while the results tentatively suggest that small projects are more likely than large ones to cite the US as a key academic partner location (although given the sample size, this is not statistically significant). Large projects are more likely to involve academic and industrial partners in France. Involvement of industrial partners in Spain and Italy show little variation with project scale while the academic partners from these locations are more likely to be involved in large projects.

TABLE 14: TOP PARTNER LOCATIONS FOR DIFFERENT SIZE BANDS OF INTERNATIONAL MANUFACTURING COLLABORATIONS (% RESPONDENTS)

Country/region	Top 3 academic partner locations				Top 3 industry partner locations			
	Size of project (cost)			Sig.[a]	Size of project (cost)			Sig.[a]
	Small	Medium	Large		Small	Medium	Large	
Germany	24	57	62	***	19	34	48	*
France	15	11	35	*	4	13	27	*
USA	41	29	18		19	22	12	
Italy	6	6	18	†	15	16	27	
Netherlands	6	26	12	*	12	9	21	
Scandinavia	18	14	21		4	9	18	
Spain	6	9	21		23	22	24	
Rest of Europe	21	17	24		15	6	15	
China	12	9	3	†	4	3	6	
Switzerland	0	9	9		0	9	6	
Australia & New Zealand	9	6	3		0	0	0	
Ireland	3	14	9		0	3	3	
Japan	18	9	0	**	8	6	0	
Belgium & Luxembourg	9	11	6		8	13	6	
India	9	9	3		0	6	0	
Canada	12	3	0	*	12	0	0	**
Rest of East/South East Asia	9	6	3		0	6	3	
Brazil	6	0	0	†	4	0	0	
Russia	0	0	6	†	0	0	3	
Middle East	3	0	0		4	3	3	
Africa	0	0	3		0	0	0	
Rest of Americas	3	0	0		0	0	0	
Rest of Central Asia	0	0	0		0	0	0	
Number of respondents	34	35	34		26	32	33	

a Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level
Source: CSTI survey of manufacturing researchers 2015

In subsequent sections of the report, the types of activities that academic and industrial partners engage in from the different locations are analysed along with the motivations for involving these partners. To enable a meaningful analysis given the sample size available, the countries and regional groups identified in the survey were clustered into the following groupings:

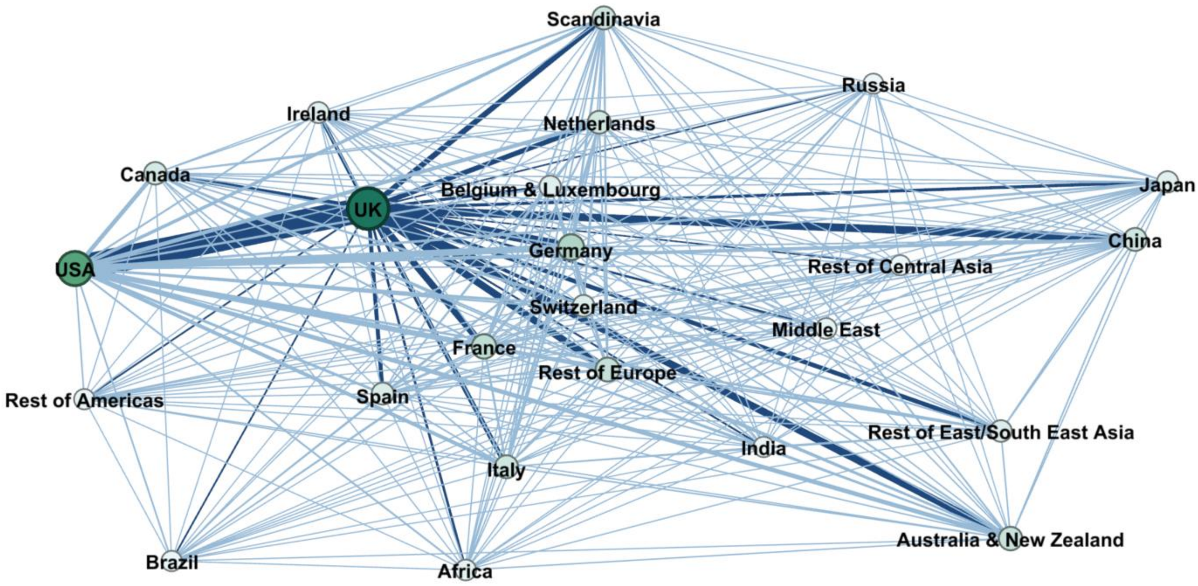
- USA
- Germany
- France, Spain and Italy (large European economies)
- Scandinavia, Benelux & Ireland (smaller open economies in the north west of Europe)
- Rest of Europe
- Developing east, south east and south Asian economies (including China and India)
- Other (including Japan, Australia & New Zealand, Canada, Brazil, Russia etc.)

Visualising the location of the UK's IMRC

Two networks maps we generated to visualise the connections between UK manufacturing researchers and their international collaborators. Figure 11 was generated from the bibliometric data obtained from Thomson Reuters Web of Science database of scholarly papers published by the EPSRC's manufacturing the future portfolio's 1,005 principle and co-investigators with international collaborators (19,565 publications). A network map visualising the connections between countries based on the IMRC's surveyed was also created (Figure 12).

The two network maps can be contrasted to compare the two samples of UK international manufacturing research collaborations, one sample based on co-publication and the other based on the survey results. It is clear that the map reflecting the links based on co-publications is more comprehensive (far more links). The differences between the network maps suggest that there are likely to be fundamental differences between the populations of the two forms of international collaboration.

FIGURE 11: NETWORK MAP OF THE CONNECTIONS BETWEEN COUNTRIES BASED ON PUBLICATIONS THAT HAVE AT LEAST ONE UK PRINCIPLE OR CO-INVESTIGATOR FROM THE EPSRC'S MANUFACTURING THE FUTURE AND AT LEAST ONE NON-UK CO-AUTHOR

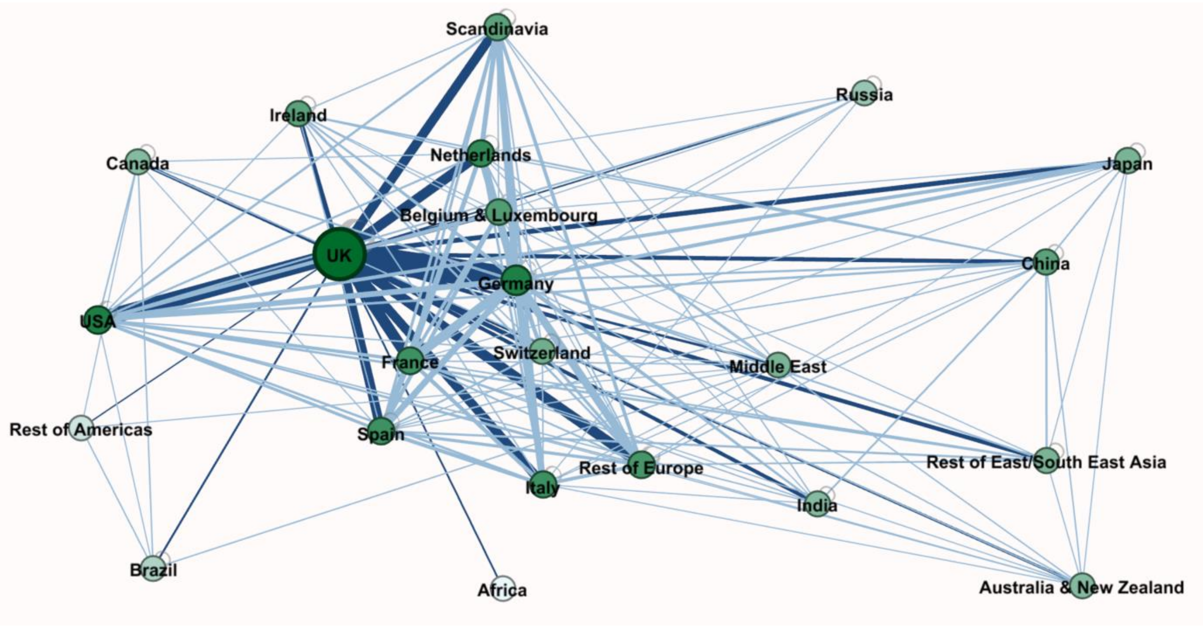


Key: The darker lines are the direct links between UK authors and overseas authors and the lighter lines are the other international connections based on those publications. The colour and size of nodes are proportional to the number of papers published; the darker and bigger the node the greater the number of connections the country has based on the 19,565 publications.

Contrasting the maps suggests that the US is under-represented in large-scale collaborative projects and that Europe appears to be over-represented, compared to authorship in co-publications. This could be because the survey focused on directly funded research collaborations, which includes EU funding, whereas publications with international co-authors are not necessarily tied directly to internationally funded projects.

Another reason why this might be the case is geographical distance. Large scale collaborations, like those surveyed, often require the coordination and transfer of resources, which is made far easier by proximity. Co-authoring publications, however, does not always require such strong and frequent connections, and often happen over a shorter period, making geographic proximity less significant.

FIGURE 12: NETWORK MAP OF THE CONNECTIONS BETWEEN COUNTRIES BASED ON THE LOCATION OF PARTNERS IN THE IMRCS SURVEY



Key: The darker lines are the direct links between UK authors and overseas authors and the lighter lines are the other international connections based on the surveyed IMRCs. The colour and size of nodes are proportional to the number IMCRs a country is involved in; the darker and bigger the node the greater the number of connections the country has through IMRCs.

6. Motivations for bringing partners into collaborative research projects

Key points from this section

The survey results suggest:

- the main motivations for UK manufacturing researchers to partner with key UK and international
    - academics partners for research expertise and know-how, access to funding, and highly specialised facilities and equipment
    - industrial partners include research expertise and know-how, manufacturing expertise and know-how, and access to funding
- established relationships and working with the best researchers globally also feature significantly
- almost all other motivations feature in close to or fewer than 25% of the collaborations surveyed
- countries appear to have 'strengths' reflected by more common reasons for partnering with their academics (e.g., Germany: Highly specialised facilities & equipment; USA: Research expertise & know-how and working with the best researchers globally); however each of these have varying country groupings coming a close second
- The frequency of motivations for bringing on European industrial partners are every similar and the US profile is very different. An exception is that Germany was never cited as being brought on to provide human resources or help project or risk management, making it in these areas more like the USA

Governments support international collaborations because they provide the scope of resources required to tackle particular problems (e.g., Cabinet Office, 1993). Furthermore, it is increasingly being recognised that international collaborations are a mechanism for bringing together the various contributions that need to be integrated to tackle 'global' societal (grand) challenges (EPSRC, 2014).

The workshop revealed that researchers engage in collaborations to combine their respective strengths and resources to conduct research that might not be able to done, or would at least be far more difficult, without research partners. Other, non-research outcome-oriented reasons also exist, such as monetary incentives by central governments aimed at building closer ties with other countries.

In the survey, respondents were asked to indicate their individual motivations for developing collaborations with their top two academic and industrial partners (Table 15). Such questions omitted engaging in collaborations for political reasons, but included non-research specific factors, including established relationships, research exploitation, and market and commercialisation reasons.

The results suggest that the motivations for being involved in IMRCs varied significantly. UK manufacturing researchers were motivated to partner with (UK and international) academics for research expertise and know-how, access to funding, and highly specialised facilities and equipment. This was closely followed by being motivated by established relationships, suggesting a desire to maintain current links or relational inertia, possibly due to existing understanding and trust or the difficult to find and build these with new partners.

TABLE 15: MOTIVATIONS FOR COLLABORATING WITH PARTICULAR ACADEMIC AND INDUSTRIAL PARTNERS

Motivation	IMRCs (% respondents)		Sig.[a]
	Academic	Industrial	
Access to funding	69	63	
Raw materials	22	26	
Highly specialised facilities & equipment	65	45	***
Large scale facilities & equipment	31	43	*
Research expertise & know-how	88	66	***
Manufacturing expertise & know-how	45	64	***
Deployment expertise & know-how	27	37	†
IP & access to technologies	24	22	
Established relationships	61	49	†
Working with the best researchers globally	55	24	***
Access to supply chain	16	16	
Access to target user community	25	22	
Market/industry intelligence	24	30	
Enhances legitimacy / reputation	24	19	
Availability of human resources	16	9	†
Project & risk management for collaborations	12	9	
Links with that country required for research	21	10	**
Scale/risk of research requires collaboration	21	18	
Commercialisation expertise	18	24	
To apply research outputs in that country/region	17	14	
Other	1	1	
Number of respondents	100	91	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

The main motivations cited for UK manufacturing researchers to partner with their key (UK and international) industrial partners include research expertise and know-how, manufacturing expertise and know-how, and access to funding. Manufacturing expertise and know-how reflects where one might expect industry to have particular strengths. The similarity of the first and last of these motivations to the motivations for engaging with academic partners indicates just how important these complementary assets are being seen for manufacturing research (almost half of all respondents to the survey, including those without international collaborations, cited these as motivations for engaging internationally). Furthermore, they suggest that partners are being involved to complement skills and augment funding to enhance research, rather than to expand human resources or gain access to countries required for research. UK academics also tend not to engage with industry (in the UK or internationally) to work with the best researchers globally, and this motivation is lower than might be expected among academic partners.

The final four tables in this section are breakdowns of this table by partner composition (Table 16), funding type (Table 17) and by the location of academic partners (Table 18) and industrial partners (Table 19).

Table 16: Motivations for collaborating with particular academic and industrial partners based on partnership composition

Motivation	Academic partners (% respondents)				Industrial partners (% respondents)			
	Academic dominated	Balanced	Industry dominated	*Sig.*[a]	Academic dominated	Balanced	Industry dominated	*Sig.*[a]
Access to funding	77	66	63		59	63	67	
Raw materials	31	17	13		30	34	11	**
Highly specialised facilities & equipment	56	77	63		37	49	44	
Large scale facilities & equipment	26	43	21	†	37	43	44	
Research expertise & know-how	82	97	83	†	59	66	70	
Manufacturing expertise & know-how	28	57	54	**	59	71	59	
Deployment expertise & know-how	28	20	33		33	34	41	
IP & access to technologies	23	20	29		15	20	30	
Established relationships	62	57	63		37	49	63	
Working with the best researchers globally	54	57	50		15	23	33	
Access to supply chain	13	14	21		15	9	26	
Access to target user community	10	34	33	**	22	14	30	
Market/industry intelligence	15	23	38	†	33	26	30	
Enhances legitimacy / reputation	15	29	29		19	17	19	
Availability of human resources	15	14	17		4	11	7	
Project & risk management for collaborations	5	17	13		4	9	11	
Links with that country required for research	26	14	21		4	11	11	
Scale/risk of research requires collaboration	15	31	13	†	4	17	30	**
Commercialisation expertise	15	20	17		30	26	15	
To apply research outputs in that country/region	15	23	8		11	14	15	
Other (please specify):	3	0	0		0	3	0	
Number of responses	39	35	24		27	35	27	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Manufacturing expertise appears to be highest when the ratio of academic and industrial partners are relatively balanced (Table 16), possibly reflecting the lower attention of academic dominated collaborations on developing later stage, closer to manufacturing deployment outputs (see Table 25 in Chapter 8). Such a possible explanation does not hold for industry dominated collaborations, however, since there are more academic partners, it is less likely that each partner will be brought into the collaboration specifically for their manufacturing expertise and know-how. Manufacturing expertise and know-how, unsurprisingly, is an infrequent motivation for involving academic partners in academic dominated collaborations.

Table 17: Motivations for collaborating with particular academic and industrial partners by funding source

Motivation	Academic partners (% of respondents)					Industrial partners (% of respondents)				
	Funding source:					Funding source:				
	Public funded	Minor industry	Major industry	Other	*Sig.*[a]	Public funded	Minor industry	Major industry	Other	*Sig.*[a]
Access to funding	64	73	75	72		50	79	82	67	*
Raw materials	16	33	31	22		24	29	35	25	
Highly specialised facilities & equipment	60	87	75	50	†	41	50	59	42	
Large scale facilities & equipment	24	47	44	22		37	50	59	42	
Research expertise & know-how	82	87	100	94		59	79	71	75	
Manufacturing expertise & know-how	44	60	44	33		72	64	53	58	
Deployment expertise & know-how	24	33	31	28		39	43	29	42	
IP & access to technologies	24	33	31	11		17	21	41	17	
Established relationships	56	73	75	56		48	43	53	67	
Working with the best researchers globally	46	67	69	61		17	43	24	33	
Access to supply chain	14	20	25	11		13	21	18	25	
Access to target user community	28	33	31	0	*	17	50	12	25	**
Market/industry intelligence	20	27	50	6	**	28	36	35	25	
Enhances legitimacy / reputation	20	33	38	17		13	36	29	8	†
Availability of human resources	10	27	25	11		4	14	18	8	
Project & risk management for collaborations	12	13	19	6		4	14	18	8	
Links with that country required for research	18	20	31	22		2	29	18	8	**
Scale/risk of research requires collaboration	20	40	13	17		17	43	6	8	**
Commercialisation expertise	18	13	38	6	†	22	29	35	17	
To apply research outputs in that country/region	18	13	25	11		15	14	12	17	
Other (please specify):	0	0	6	0		2	0	0	0	
Number of responses	50	15	16	18		46	14	17	12	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

While commercial expertise is a common motivation for involving industry partners in academic dominated collaborations, motivations such as access to human resources, risk management, links to the country, and were collaborations may help with the scale and risks of research do not feature in getting industrial partners to join such collaborations.

Interestingly, when industry funding is involved, access to highly specialised facilities becomes an important motivation for academic partner inclusion (Table 17). In addition, projects with industry as a major source of funding are more likely than other projects to involve academic partners because of their market or industry intelligence as well as their commercialisation expertise. This suggests that when industry is a major funder, much greater emphasis is placed on the academic partner capabilities to both understand markets and how to commercialise technologies. Where industry is a minor funder alongside significant public funds, industrial partners are more likely than in other cases to be brought into collaborations because the research requires either scale or is too risky to do alone. This is consistent with the view that such research projects will struggle to get significant industry funding due to their risk profiles and require public funding to lead the way.

The main motivations for involving partners in particular countries appear to be relatively consistent across locations (Table 18 and Table 19). The notable exception is in research expertise and know-how, where the US and France, Spain, and Italy feature very strongly. This is less important for involving partners from the rest of Europe, and developing E/SE/S Asia.

Other variations in motivation include the low contribution of German academic partners to raw materials; the frequent motivation to involve academic partners from the UK, Germany, France, Spain, and Italy to gain access to highly specialised equipment; and the large scale facilities in the UK, the rest of Europe, and developing E/SE/S Asia. Germany was also rarely brought into a collaboration for non-technological, non-know-how, and non-existing relationship motivations.

The most common motivations for bringing academic partners into a collaboration from the developing E/SE/S Asia economics match the motivations for all academic partners, with the exception (lower frequencies in) established relationships. However, outside of these motivations, these economies drop off significantly compared to other countries, except for the (aforementioned) large scale facilities and human resources.

The variation in motivations for involving industrial partners in collaborations is rather more noticeable (Table 19). Perhaps the most obvious trend is that European industrial partners are frequently brought into collaborations from the research expertise and know-how, manufacturing expertise and know-how, and because of established relationships. This may be because of the EU and because of the close proximity and historical links to these countries. German industrial partners have also been brought in to help tackle the scale and risk involved in manufacturing research projects and so that research outputs can be applied in Germany.

The main motivation for involving North American industrial partners is access to funding, which aligns with strength of their business investments in R&D. The results provided similar frequencies for developing E/SE/S Asia and while the low number of responses reduces the confidence with which conclusions can be drawn, this also seems to complement the rapid growth and expanding nature of these economies in recent years.

The relatively even distribution of bringing industrial partners into a collaboration to work with the best researchers globally indicates that world class researchers may be anywhere in the world, and not only located in large industrial economies. Collaborations then, may need to be with a variety of these country groupings to call on the best researchers globally.

TABLE 18: MOTIVATIONS FOR COLLABORATING WITH PARTICULAR ACADEMIC PARTNERS BASED ON LOCATION

Motivation	Academic partners (% respondents)								Sig.[a]
	UK	USA	Germany	France, Spain & Italy	Scandinavia, Benelux & Ireland	Rest of Europe	Developing E/SE/S Asian Economies	Other	
Access to funding	68	55	42	60	52	47	69	36	**
Raw materials	12	23	3	12	24	18	19	29	
Highly specialised facilities & equipment	51	32	56	44	31	47	38	36	
Large scale facilities & equipment	23	14	11	8	14	29	25	14	
Research expertise & know-how	79	95	72	92	83	65	63	57	**
Manufacturing expertise & know-how	37	32	39	32	31	29	13	29	
Deployment expertise & know-how	19	36	14	16	31	24	13	43	†
IP & access to technologies	19	14	17	16	24	12	0	21	
Established relationships	55	55	44	56	55	47	19	57	
Working with the best researchers globally	47	68	47	48	48	35	38	71	
Access to supply chain	8	5	3	8	17	12	13	7	
Access to target user community	19	27	11	28	21	24	6	29	
Market/industry intelligence	17	32	3	4	14	18	0	36	
Enhances legitimacy / reputation	23	27	11	20	17	12	6	29	
Availability of human resources	12	9	3	16	10	12	19	21	
Project & risk management for collaborations	9	14	3	8	7	6	6	14	
Links with that country required for research	16	18	8	20	14	12	6	50	**
Scale/risk of research requires collaboration	19	14	19	16	24	12	6	29	
Commercialisation expertise	13	27	6	12	10	6	6	14	
To apply research outputs in that country/region	15	5	11	16	21	12	6	14	
Other	1	5	0	0	0	0	0	7	
Number of responses	98	22	36	25	29	17	16	14	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level
Source: CSTI survey of manufacturing researchers 2015

TABLE 19: MOTIVATIONS FOR COLLABORATING WITH PARTICULAR INDUSTRIAL PARTNERS BASED ON LOCATION

Motivation	Industrial partners (% respondents)								Sig.[a]
	UK	USA	Germany	France, Spain & Italy	Scandinavia, Benelux & Ireland	Rest of Europe	Developing E/SE/S Asian Economies	Other	
Access to funding	66	82	52	53	29	44	80	57	*
Raw materials	22	36	9	9	24	11	60	14	*
Highly specialised facilities & equipment	32	45	30	38	35	33	20	29	
Large scale facilities & equipment	36	45	35	28	53	11	40	29	
Research expertise & know-how	54	36	65	59	76	56	20	29	
Manufacturing expertise & know-how	51	36	70	53	71	67	20	29	
Deployment expertise & know-how	33	27	22	25	24	22	20	43	
IP & access to technologies	16	9	13	9	12	44	20	14	
Established relationships	47	9	35	50	65	56	20	14	**
Working with the best researchers globally	26	27	26	22	29	22	20	14	
Access to supply chain	16	0	9	9	12	0	20	14	
Access to target user community	25	18	17	22	18	0	20	29	
Market/industry intelligence	28	18	26	25	18	0	20	14	
Enhances legitimacy / reputation	20	9	9	22	18	0	20	0	
Availability of human resources	9	0	0	16	12	0	20	0	
Project & risk management for collaborations	9	0	0	9	12	0	20	0	
Links with that country required for research	11	18	9	6	18	11	20	14	
Scale/risk of research requires collaboration	17	9	22	16	12	0	20	14	
Commercialisation expertise	21	18	13	19	24	11	20	14	
To apply research outputs in that country/region	13	9	26	19	18	22	20	0	
Other	1	0	0	0	0	0	0	14	
Number of responses	76	11	23	32	17	9	5	7	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Finally, the motivations that were infrequently cited indicate that particular characteristics of academics and industrialists, particularly in specific country groupings, may not be particularly valued in international manufacturing research collaborations. Getting access to the supply chain and to enable the application of research outputs in a country grouping were both infrequent motivations, for bringing both academic and industrial partners into a collaboration. Human resources and project and risk management were consistently low across industrial partners; and it is surprising that none of the responses identifying partners in the US and Germany cited as being brought into a collaboration for these reasons.

7. Partner contributions to project activities in collaborative projects

Key points from this section

The survey results suggest:

- early applied research is the most frequently cited activity in international manufacturing research collaborations
- not all international manufacturing research collaborations are conducting activities in basic (fundamental or early stage) research
- most of the activity of international manufacturing research collaborations is in developing knowledge that might find its way into novel products, processes, and services
- the key supporting tasks international manufacturing research collaborations are conducting are in developing simulation and modelling and developing measurement and testing tools or providing measurement and testing services, which is most often conducted by academic partners
    - in contrast, while East, South-East, and South Asian academics were frequently cited as contributing to basic and early applied research, they almost never contributed to wider value chain, innovation and industry infrastructure, and informing policy and supporting standards development activities
- industrial partners contribute much more to activities focused on mid-technology readiness levels and generally contribute very little to innovation and industry infrastructure and informing policy and supporting standards development
    - in particular, US industrial partners are very rarely brought on to support activates outside of direct development activities

The project activities undertaken by different project partners in a collaboration provide some indications on how they contribute to the delivery of the project's output and the contributions these partners may make in the future. Furthermore, they provide additional insight into the reasons for bringing particular partners into the collaboration. The activities to which partners contribute were characterised based on contributions to various stages of development in a technology life cycle (innovation chain), other value chain activities, innovation and industry infrastructure, and the external environment. The results of these divided by academic and industrial partners is shown in Table 20.

The survey results suggest that not all academics conduct activities in IMRCs that are generating basic knowledge and they conduct activities through all stages of the innovation process. Furthermore, more than half of industry partners are contributing to fundamental research. However, the centre of gravity for these two groups are where one might expect, with academic activity centring on earlier development and industry focusing on slightly later development. Perhaps most striking is that the difference between academic and industrial partner activities does not significantly vary, particularly outside basic research.

TABLE 20: PROJECT ACTIVITIES BY ACADEMIC AND INDUSTRIAL PARTNERS

Project activity		IMRCs (% respondents)			Sig.[a]
		Academic	Industrial	Difference	
Stage of innovation	Basic research	84	59	-25	***
	Early applied research	89	70	-19	***
	Development	62	74	12	*
	Demonstrating technologies in a relevant environment	55	53	-3	
	Deployment in pilot lines	28	32	5	
	Full deployment	14	24	10	*
Wider value chain activities	Developing manufacturing practices & protocols	33	31	-1	
	Operations/supply chain	18	18	0	
	Management practices	11	13	2	
	Managing risk reduction	16	14	-2	
Innovation & industry infrastructure	Developing/providing measurement and testing tools	42	31	-10	†
	Developing simulation & modelling	55	25	-31	***
	Developing & delivering training programmes	30	16	-14	**
	Incubating technologies / providing space for exploring commercial potential of ideas	17	11	-6	
	Collecting and collating industry & market intelligence	14	17	3	
	Seeding clusters of activity / communities of practice	15	17	2	
	Building networks & linkages	34	24	-10	†
External environment	Informing / shaping policy	18	13	-5	
	Informing / shaping standards & regulations	13	13	0	
Other		1	2	1	
Number of responses		101	93		

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Just as striking is the relatively similar contributions academic and industrial partners are making to collaborations, as can be seen in Table 20, except in simulation and modelling. This suggests there is a significant difference between academic and industrial partners in capability, inclination, or both to contribute to the simulation and modelling activities in international manufacturing research collaborations. It also leads to the conclusion that, by comparison at an aggregate level, the capability, willingness or both to contribute to other areas of the collaboration are relatively evenly distributed between academic and industrial partners.

It is also noticeable how little activity is occurring in the international manufacturing research collaborations in management practises, managing risk reduction, incubating technologies, developing market intelligence, seeding clusters of activities, information policy development, and informing the development of standards and regulations. It is possible that this arises from the focus of the researchers surveyed (basic and applied researchers), which tends to be further from the market and their focus on advancing manufacturing research, rather than wider value chain activities, innovation and industry infrastructure, and shaping the external environment.

The final four tables in this section are breakdowns of this table by partner composition (Table 21), funding sources (Table 22), and by location of academic partners (Table 23) and location of industrial partners (Table 24).

TABLE 21: PROJECT ACTIVITIES BY ACADEMIC AND INDUSTRIAL PARTNERS IN VARIOUS PARTNERSHIP COMPOSITIONS

Project activity		Academic partners (% respondents)				Industrial partners (% respondents)			
		Academic dominated	Balanced	Industry dominated	Sig.[a]	Academic dominated	Balanced	Industry dominated	Sig.[a]
Stage of innovation	Basic research	85	86	79		57	56	62	
	Early applied research	90	89	88		75	65	69	
	Development	54	67	67		79	65	79	
	Demonstrating technologies in a relevant environment	56	50	58		36	47	72	**
	Deployment in pilot lines	18	28	38		14	41	34	*
	Full deployment	10	11	17		7	26	31	*
Wider value chain activities	Developing manufacturing practices & protocols	23	36	42		25	29	38	
	Operations/supply chain	21	14	17		11	21	21	
	Management practices	5	14	13		4	15	17	
	Managing risk reduction	13	14	21		11	12	17	
Innovation & industry infrastructure	Developing/providing measurement and testing tools	38	36	50		29	35	28	
	Developing simulation & modelling	46	56	67		25	24	24	
	Developing & delivering training programmes	23	36	29		11	21	14	
	Incubating technologies / providing space for exploring commercial potential of ideas	21	11	17		11	6	14	
	Collecting and collating industry & market intelligence	13	11	17		11	12	28	†
	Seeding clusters of activity / communities of practice	10	14	21		11	21	17	
	Building networks & linkages	33	31	38		14	24	31	
External environment	Informing / shaping policy	23	14	13		11	12	14	
	Informing / shaping standards & regulations	13	11	13		11	12	14	
Other		0	0	4		4	0	3	
Number of responses		39	36	24		28	34	29	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

TABLE 22: PROJECT ACTIVITIES BY ACADEMIC AND INDUSTRIAL PARTNERS FOR DIFFERENT FUNDING SOURCES

Project activity		Academic partners (% of respondents)					Industrial partners (% of respondents)				
		Public funded	Minor industry	Major industry	Other	Sig.[a]	Public funded	Minor industry	Major industry	Other	Sig.[a]
Innovation chain	Basic research	86	73	94	79	***	46	60	82	85	**
	Early applied research	86	87	100	89		65	73	82	69	
	Development	68	80	81	16		76	87	65	69	
	Demonstrating technologies in a relevant environment	54	73	63	42		50	67	53	46	
	Deployment in pilot lines	24	33	38	26		33	40	24	38	
	Full deployment	12	20	25	5		17	33	29	31	
Wider value chain activities	Developing manufacturing practices & protocols	30	40	50	16	***	30	40	29	31	
	Operations/supply chain	12	47	25	5		17	27	18	15	
	Management practices	10	13	19	5		11	7	24	15	
	Managing risk reduction	18	13	25	5		9	20	24	15	
Innovation & industry infrastructure	Developing/providing measurement and testing tools	38	60	38	42	*	28	40	29	38	
	Developing simulation & modelling	50	87	50	47		22	47	18	23	
	Developing & delivering training programmes	32	33	25	26		15	20	24	8	
	Incubating technologies / providing space for exploring commercial potential of ideas	14	20	31	11		9	20	12	8	
	Collecting and collating industry & market intelligence	18	20	13	0		15	20	24	15	
	Seeding clusters of activity / communities of practice	10	27	19	11		11	20	24	31	
	Building networks & linkages	32	47	38	26		20	33	29	23	
External environment	Informing / shaping policy	18	20	19	16		9	13	29	8	
	Informing / shaping standards & regulations	14	13	13	11		9	13	18	23	
Other (please specify):		0	7	0	0	†	2	7	0	0	
Number of responses		50	15	16	19		46	15	17	13	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Academic partners in projects with industry as a major source of funding are more likely than others to engage in development activity. However, interestingly industrial partners are more likely to be engaged in basic research as industry funding becomes a key source of income. Although not statistically significant given the small samples involved, the same appears true of applied research. In addition, although not statistically significant, academics in projects with public funding as the only dominate source appear less likely than those projects with industry funding to undertake development and demonstration and pilot line deployment activities. Further work would be required to confirm these findings.

In simulation and modelling academic activities increase with greater industry involvement; suggesting that this may be a central reason why academic partners are engaged in collaborations. However, variations across other areas of contribution are small. One point of possible significance is that academic partners play a roughly even role in building networks and linkages through all partner composition types, whereas industrial partners play a very small role in building linkages in academic dominated collaborations.

Dividing the responses to project activities by the project funding sources reveals other characteristics (Table 22). All academic partners in collaborations where industry is a major funder of the collaboration conduct activities in early applied research. Furthermore, academic activities in operations/supply chain and developing simulation and modelling tools peak in collaborations where industry is a minor funder, and the former drops significantly in publicly funded collaborations. Of significance is industrial partner activities in basic research, which is *lowest* in publicly funded collaborations.

When broken down by country groupings consistency across countries with respect to their contributions to collaborations appears to be a trend for academic partners (Table 23). Contributions of country groupings to basic research and early applied research are quite consistently high across country groupings. Contributions by academic partners are consistently low in managing risk reduction, collecting and collating industry and market intelligence, and incubating technologies. An obvious exception is the low contribution of East, South-East, and South Asian academic partners to almost all activities outside of the basic research and early applied research.

TABLE 23: PROJECT ACTIVITIES BY ACADEMIC PARTNER LOCATION

Project activity		Academic partners (% respondents)								Sig.[a]
		UK	USA	Germany	France, Spain & Italy	Scandinavia, Benelux & Ireland	Rest of Europe	Developing E/SE/S Economies	Other	
Stage of innovation	Basic research	82	65	46	58	64	65	76	67	***
	Early applied research	87	70	78	71	71	76	71	53	*
	Development	51	39	54	42	46	47	35	27	
	Demonstrating technologies in a relevant environment	44	39	43	38	61	41	18	40	
	Deployment in pilot lines	17	17	19	21	18	29	6	7	
	Full deployment	10	9	5	8	18	24	0	7	
Wider value chain activities	Developing manufacturing practices & protocols	26	13	19	21	11	24	6	27	
	Operations/supply chain	14	9	5	4	21	18	6	13	
	Management practices	8	9	5	8	25	18	0	7	*
	Managing risk reduction	14	13	8	8	11	18	6	0	
Innovation & industry infrastructure	Developing/providing measurement and testing tools	35	30	35	21	36	29	12	7	
	Developing simulation & modelling	47	30	38	38	29	24	18	13	*
	Developing & delivering training programmes	24	13	11	29	29	29	0	20	†
	Incubating technologies / providing space for exploring commercial potential of ideas	10	17	5	13	14	18	0	7	
	Collecting and collating industry & market intelligence	9	9	8	8	14	18	0	13	
	Seeding clusters of activity / communities of practice	12	9	8	4	21	24	0	7	
	Building networks & linkages	31	30	22	29	32	41	18	53	
External environment	Informing / shaping policy	17	9	8	13	18	18	0	13	
	Informing / shaping standards & regulations	9	4	16	13	11	18	0	7	
Other		1	0	3	4	0	0	0	0	
Number of responses		100	23	37	24	28	17	17	15	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Table 24: Project activities by industrial partner location

Project activity		Industrial partners (% respondents)								Sig.[a]
		UK	USA	Germany	France, Spain & Italy	Scandinavia, Benelux & Ireland	Rest of Europe	Developing E/SE/S Economies	Other	
Stage of innovation	Basic research	58	69	38	34	45	10	67	44	*
	Early applied research	58	62	46	72	55	20	67	44	
	Development	64	46	58	75	80	40	50	56	
	Demonstrating technologies in a relevant environment	39	46	46	47	50	35	33	33	
	Deployment in pilot lines	26	23	21	19	45	35	17	11	**
	Full deployment	18	15	17	13	25	25	17	11	
Wider value chain activities	Developing manufacturing practices & protocols	23	15	25	16	35	15	17	22	
	Operations/supply chain	18	8	0	16	15	10	17	11	
	Management practices	16	0	0	13	15	5	17	11	
	Managing risk reduction	14	0	4	16	15	0	17	0	
Innovation & industry infrastructure	Developing/providing measurement and testing tools	27	8	21	34	20	5	17	11	
	Developing simulation & modelling	26	15	25	28	10	5	17	22	
	Developing & delivering training programmes	17	0	13	16	20	5	17	0	
	Incubating technologies / providing space for exploring commercial potential of ideas	10	0	4	6	20	5	17	0	
	Collecting and collating industry & market intelligence	14	0	4	16	20	10	17	0	
	Seeding clusters of activity / communities of practice	19	8	8	16	15	10	17	11	
	Building networks & linkages	26	23	17	19	20	10	50	22	
External environment	Informing / shaping policy	16	8	4	9	15	5	17	0	
	Informing / shaping standards & regulations	10	0	8	9	5	5	17	0	
Other		1	0	0	0	0	0	0	11	
Number of responses		77	13	24	32	20	9	6	9	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Industrial contributions to collaborations vary somewhat more (Table 24). Scandinavia, Benelux, and Ireland contribute much more broadly than other countries to the collaborations surveyed. The rest of Europe and the US have very small contributions from industry outside of contributions to stages of innovation. In the case of the US this is particularly surprising in the instances of incubation and industry and market intelligence, given its record in innovation and entrepreneurship; and training, given its record in education and strong higher education institutions (e.g., see OECD, 2012).

8. Anticipated effects on innovation of international collaborative manufacturing research

Key points from this section

The survey results suggest:

- that a significant portion of manufacturing researchers in the UK are making immediate contributions to the science and engineering base and (enabling) tools and techniques
- that manufacturing researchers in the UK anticipate little direct impact on tool-based services and proprietary manufacturing equipment and systems
- that manufacturing researchers in academic dominated collaborations have a very focused non-technology based contribution in developing research skills and technical and manufacturing skills
- that manufacturing researchers in balanced and industry dominated collaborations believe their collaborations make significant contributions to more non-technical areas than academic dominated collaborations
- most manufacturing researchers believe their international collaborations will make contributions towards developing next generation products with a step change in functionality, and towards increasing the quality and reducing the cost of manufactured products

To get an idea of the outputs of IMRCs and their impact, several questions about the anticipated direct effects of the collaborations were asked. These were divided into their anticipated technology and non-technology based contributions and their anticipated impact on final products. The variety of technology types explored is outlined in Box 1. With the last of these in particular, there is a certain degree of uncertainty in the responses because of the uncertain impact that because of the multiple pathways through which impact could be realised and the multiple factors and length of time involved. Given the more immediate contributions of research projects on technology and non-technology based contributions (e.g. on skills in the UK), there is likely to be less uncertainty around the responses about the anticipated technology and non-technology based contributions.

Anticipated technology and non-technology based contributions

Anticipated technology based contributions

The survey results of the anticipated technology based contributions (Table 25) of international manufacturing research collaborations indicates that a most collaborations are making contributions to the science and engineering research base and to (enabling) tools and techniques. This not only reflects the focus of the researchers targeted to complete the survey (EPSRC funded researchers), but also demonstrates that the mostly researcher contribution of providing measurement and testing tools and simulation and modelling to collaborations (c.f. Table 20) end up being a key technical contribution of the collaboration. The portion of collaborations making contributions to areas of technology based knowledge areas decrease as the knowledge becomes more and more directly linked to products, processes, services, or systems that are commercialisable, as might be expected. Furthermore, the high portion of collaborations surveyed that are making a contribution to (enabling) tools and techniques suggests that international manufacturing research collaborations are a mechanism for developing these tools and techniques, which is argued to be essential for the advancement of science and technology (e.g., see Tassey, 2005).

BOX 1: DEFINING DIFFERENT TYPES OF TECHNOLOGIES

Science & engineering research base (*advancing core knowledge underpinning the development of applications*):

- Science underpinning technology: the fundamental science underpinning the technology
- Science needed in support of bespoke applications: further research required for integration and adaptation into novel product systems

Tools & techniques (*technical capabilities that enable or support R&D*):

- Modelling, design, data analysis & data verification: Underlying infrastructure in support of design and data analysis
- Measurement, characterisation & testing: Underlying infrastructure that enables accurate measurement, characterisation, and testing

Platform technologies (*technologies ending up embedded in a variety/number of final products, or a number of final production / process systems*):

- Product-enabling technologies: Technologies deployed in the product itself
- Production & process enabling technologies: Application technologies supporting product development

Applications & markets (*bespoke or proprietary technologies embedded in actual service-tools, manufacturing equipment / systems or commercialisable*)**:**

- Tool-based services: Technology-based tools leading to a market on their own
- Proprietary manufacturing equipment and systems
- Products & applications: Proprietary applications intended for sale

A number of other observations stand out. First, very few collaborations surveyed anticipate making a contribution to tool based services. Second, a relatively high number of collaborations focus on products and applications and far fewer focus on proprietary manufacturing equipment and systems, except when manufacturing collaborations are roughly equal in academic and industry collaborators. Given the UK government's desire to realise the benefits of its funding of research, it is surprising that international manufacturing research collaborations (many of which here receive such funding) anticipate significantly more impact on products and applications than on manufacturing equipment and systems.

Table 25: Immediate contributions of various partnership compositions to technology based knowledge areas

Anticipated effects		Anticipated effects % respondents)				
		All IMRCs	Academic dominated	Balanced	Industry dominated	Sig.[a]
Science and engineering research base	Science underpinning technology	82	80	89	73	
	Application enabling science	75	80	81	60	*
Platform technologies	Product-enabling platform technologies	43	35	47	50	
	Production-enabling platform technologies	37	30	42	40	
Applications & markets	Tool-based services	7	5	6	10	
	Products & applications	29	23	33	33	
	Proprietary manufacturing equipment & systems	18	10	31	12	**
Tools & techniques	Modelling, data analysis & data verification	60	53	64	60	
	Measurement, characterisation & test	75	65	81	80	
Other		1	3	0	0	
Number of respondents		109	40	36	30	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Table 26: Immediate contributions to technology based knowledge areas for projects funded through different sources

Anticipated effects		Anticipated effects anywhere					
		All IMRCs	Public funded	Minor industry	Major industry	Other	Sig.[a]
Science and engineering research base	Science underpinning technology	82	83	67	83	90	
	Application enabling science	75	64	87	83	86	*
Tools & techniques	Modelling, data analysis & data verification	60	58	80	61	48	
	Measurement, characterisation & test	75	70	73	89	76	
Applications & markets	Tool-based services	7	8	7	11	5	
	Products & applications	29	32	33	28	19	
	Proprietary manufacturing equipment & systems	18	18	15	25	18	
Platform technologies	Product-enabling platform technologies	43	40	47	61	33	
	Production-enabling platform technologies	37	38	47	44	19	
Other (please specify):		1	0	0	6	0	
Number of respondents		109	53	15	18	21	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level

Source: CSTI survey of manufacturing researchers 2015

Collaborations that are balanced in their composition appear to contribute a broader range of categories of knowledge listed Table 25 compared with academic dominated or industry dominated collaborations (although they were more similar in profile to industry dominated collaborations than academic dominated ones). However, given the sample sizes these differences were not statistically significant. More work would be needed to establish their robustness. Similarly, few variations between projects with different funding types emerged as statistically significant other than contributions to application enabling science where projects where public funding was the only significant funding source contributed less to this area than other projects.

Anticipated non-technology based contributions

In terms of the anticipated non-technology based contributions, skills – in particular research and technical and manufacturing skills – and new product development practices and protocols dominate in the responses received. Furthermore, respondents anticipated very little contribution from their collaborations to developing new or improved manufacturing business models, informing policy development, and developing technical standards.

TABLE 27: SIGNIFICANT CONTRIBUTIONS OF VARIOUS PARTNERSHIP COMPOSITIONS TO NON-TECHNOLOGY BASED KNOWLEDGE AREAS

Other anticipated contributions	Anticipated contributions (% respondents)				
	All IMRCs	Academic dominated	Balanced	Industry dominated	Sig.[a]
Developing research skills	92	92	91	90	
Developing technical & manufacturing skills	72	72	80	59	
Developing management skills	25	18	29	31	
Developing and/or disseminating intelligence (e.g. market, supply chain, industry)	21	23	19	16	
New product development practices and protocols	44	33	52	44	
Developing new or improved manufacturing business models	12	5	14	17	
Manufacturing systems design & development	25	18	26	31	
Informing policy development	13	13	11	14	
Developing clusters/networks of manufacturing capabilities	15	15	9	21	
Creating new training manuals & courses	15	8	20	17	
Developing technical standards	14	10	11	17	
Product/technology risk reduction	21	15	23	21	
Other	1	3	0	0	
Number of respondents	106	39	35	29	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level
Source: CSTI survey of manufacturing researchers 2015

Most respondents with academic dominated collaborations anticipated their projects would contributing significantly to research and technical and manufacturing skills and a third anticipated significant contributions to new product development practices and protocols and management skills. However, a noticeable pattern in Table 27 is that academic dominated collaborations believed their contributions to be far less distributed than other collaboration compositions believed their contributions to be in terms of impact. Generally, fewer saw significant contributions in new product development practices and protocols, developing management skills, developing new of improved business models, manufacturing systems design and development than other collaboration compositions. Finally, few academic dominated collaborations anticipated contributions to a number of more 'applied' areas than other collaboration compositions, including new product development practices and protocols, creating new training manuals and courses, management skills, and developing business models. However, given the sample sizes these differences were not found to be statistically significant. Further work would be required to establish the robustness of these differences.

The top categories that balanced and industry dominated collaborations anticipated contributions to roughly matched that of academic dominated collaborations: research skills, technical and manufacturing skills, and new product development practices and protocols. The major differences between balanced and industry dominated collaborations were in technical and manufacturing skills and developing clusters/networks of manufacturing capabilities, although none of the differences were not statistically significant so caution should be used in interpreting the variations. The first of these may be for a number of reasons, including industry not seeing collaborations with lower portions of academic partners as a way of developing these skills (when it is quite similar to developing these skills in house), because these collaborations involve potential competitors, or because their attention is just focused on other areas.

Table 28 reveals important variations in anticipated non-technology contributions by projects with different funding types. First, projects with minor industry funding alongside public funding are much more likely than other projects to develop management skills. In addition, they are much more likely to be involved in developing new product development practices and protocols. Projects with industry funding as both a major and minor component are more likely than other projects to contribute to product and technology risk reduction.

TABLE 28: SIGNIFICANT CONTRIBUTIONS TO NON-TECHNOLOGY BASED KNOWLEDGE AREAS, FOR DIFFERENT FUNDING TYPES

Other anticipated contributions	Anticipated contributions anywhere					
	All IMRCs	Public funded	Minor industry	Major industry	Other	Sig.[a]
Developing research skills	92	92	93	95	90	
Developing technical / manufacturing skills	72	73	79	74	65	
Developing management skills	25	25	50	26	5	**
Developing and/or disseminating intelligence (e.g. market, supply chain, industry)	21	26	33	18	6	
New product development practices and protocols	44	40	75	47	25	*
Developing new or improved manufacturing business models	12	16	0	26	0	**
Manufacturing systems design / development	25	24	29	21	30	
Informing policy development	13	12	21	16	10	
Developing clusters/networks of manufacturing capabilities	15	10	29	16	15	
Creating new training manuals & courses	15	14	7	26	15	
Developing technical standards	14	14	14	16	15	
Product/technology risk reduction	21	14	36	37	15	*
Other (please specify):	1	0	0	0	5	
Number of respondents	106	51	14	19	20	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level
Source: CSTI survey of manufacturing researchers 2015

Anticipated effect on end-use products

As stated, anticipating the possible effects fundamental research might have on final products is difficult and responses here should be treated very carefully. Despite this uncertainty, many respondents felt they could give an indication of where their research may affect final products. In particular step changes in functionality was the most cited effect. This was followed by increasing the quality and reducing the costs of final products. The respondents saw their collaborations contributing fairly evenly to the remaining categories provided in the survey.

TABLE 29: ANTICIPATED EFFECTS ON FINAL PRODUCTS ARISING FROM THE RESEARCH BY PARTNERSHIP COMPOSITION

Anticipated effects on product functionality	IMRCs	Partner composition (% respondents)			Sig.[a]
		Academic dominated	Balanced	Industry dominated	
Functionality – radically new	35	39	38	23	
Functionality – next generation / step change	70	61	76	73	
Functionality – incremental advance	26	30	24	23	
Reduce cost	52	36	59	63	*
Increase quality	55	52	68	47	
Improve reliability/ durability	43	39	41	50	
Improve safety to the user	25	18	41	10	***
Increase desirability	20	21	21	17	
Increase usability	22	24	18	23	
Increase sustainability	45	42	50	43	
Not yet clear	2	3	0	3	
Other	2	0	3	3	
Number of respondents	100	33	34	30	

[a] Statistically significant variation amongst sub-groups at: *** at 1%; ** at 5%; * at 10%; and † at 15% level
Source: CSTI survey of manufacturing researchers 2015

Manufacturing research can have implications for more than just the processes used to produce products and for the products themselves, such as in service delivery, but further reaching questions were not asked due to survey length constraints.

9. Factors affecting exploitation of manufacturing research in the UK

Key points from this section

The survey results suggest:

- Capability, capability, and willingness of UK industrial base to absorb and deploy technology/process and appropriate factory-like facilities in the UK for testing and demonstrating technologies where the most important factors to ensure that high value manufacturing benefits from research could be exploited in the UK
- The UK is seen as strong in a number of areas that are critically important to ensure high value manufacturing benefits from research could be exploited in the UK
  - However, it was seen as weak in the willingness of UK industrial base to absorb and deploy technologies and processes.
- Earlier stages of development were more frequently cited as critical for the UK commercially exploit the benefits of respondents' collaboration
  - Early applied research was most frequently cited
- Very few (zero, one, or two respondents) saw any of the stages as not at all important to be involved in for the UK commercially exploit the benefits of respondents' collaboration

UK industry, academia, and government all have interests in ensuring that the UK has what is needed to capitalise on its strong research base. Understanding what needs to be in place is difficult because it requires a detailed understanding of academic and industrial conditions and understanding how the government can support this requires an understanding of how policy measures influence exploitation.

To capture one perspective that contributes to understanding of what needs to be in place, the survey asked respondents to identify the factors that are important for maximising the likelihood that high value manufacturing opportunities arising from their collaboration's research are exploited in the UK (the results can be seen in Table 30). To provide an indication of where attention might need to be placed, the survey also asked participants how important they believed it was to be involved in particular stages of innovation or 'commercialisation pathway' for the UK to benefit from the commercial application of the research (the results of which can be seen in Table 31, and those who responded critical can be seen categorised by their collaborations composition in Table 32).

TABLE 30: FACTORS THAT ARE IMPORTANT FOR MAXIMISING THE LIKELIHOOD THAT HIGH VALUE MANUFACTURING OPPORTUNITIES ARISING FROM THE COLLABORATION'S RESEARCH ARE EXPLOITED IN THE UK AND THE UK'S STRENGTH IN THOSE AREAS

Exploitation factor	Importance of factor in UK	Strength in UK (% respondents)			
		Very weak or weak	Neither weak nor strong	Strong or very strong	Difference between very strong & strong and very weak & weak
Appropriate factory-like facilities in UK for testing / demonstrating technologies	74	27	26	47	20
Other necessary testing facilities & equipment in UK (e.g. NPL)	48	19	27	55	36
Capacity of UK industrial base to absorb & deploy technology/process	82	33	35	33	0
Capability of UK industrial base to absorb & deploy technology/process	75	30	28	42	12
Willingness of UK industrial base to absorb, adopt & deploy technologies/process	79	41	30	29	-12
Access to key / critical mass customer markets	42	23	26	51	28
Access to key suppliers	41	21	25	54	33
Proximity / access to production facilities of industrial partners	29	20	41	39	20
Access to complementary technologies	38	18	32	50	32
Coordination of UK public support from one stage of development to the next	46	38	44	18	-20
Current level/focus of UK public investment	51	42	25	33	-9
Current ability to obtain non-public financial investment	37	45	37	18	-27
Appropriate scale & quality of research skills in UK	57	16	23	61	45
Appropriate scale & quality of manufacturing skills in UK	56	27	30	44	17
Appropriate scale / quality of management & commercialisation skills in UK	40	31	51	18	-12
Cost of labour in the UK	28	28	61	11	-17
IP regime in UK	39	17	46	37	19
Public incentives regime in UK (e.g. tax)	29	46	41	13	-33
Regulatory regime in UK	31	16	58	27	11
Number of respondents	95	101	101	101	101

Source: CSTI survey of manufacturing researchers 2015

The results suggest that the capability, capability, and willingness of UK industrial base to absorb and deploy technologies and processes, and appropriate factory-like facilities in the UK for testing and demonstrating technologies where the most important factors to ensure that high value manufacturing benefits from research could be exploited in the UK. More than half of respondents to the question of importance also cited appropriate scale and quality of manufacturing skills, appropriate scale and quality of management and commercialisation skills, and the current level and focus on UK public investment as important for exploitation in the UK. No factors listed in Table 30 were thought unimportant by less than 25% of respondents.

The relative strength of the UK was quite varied. The UK was seen as quite strong in a number of the 'most' important areas, including capability of UK industrial base to absorb and deploy technologies and processes, and appropriate factory-like facilities in the UK for testing and demonstrating technologies. It was seen as weak in the willingness of UK industrial base to absorb and deploy technologies and processes. The UK was also seen as weak in the public incentives regime, the current ability to obtain non-public financial investment, and the coordination or UK public support from one stage of development to the next. Weakness in the ability to obtain non-public financial investment is particularly surprising given the UK strong venture capital sector. The other weaknesses point to areas over which government policy has direct effects.

Of the stages of R&D that are critical to be involved in to capture value from international manufacturing research collaborations, the greatest portion of respondents believed that early applied research was critical, closely followed by basic research, and further development. A noticeable pattern is a slight fall in respondents believing the later stages of development are critical; however these respondents shift only to somewhat important.

Table 31: How important respondents believed it was to be involved in particular stages of innovation/ commercialisation pathway for the UK to benefit from the commercial application of the research

Critical to be involved in:	Share of respondents (%)			
	Not at all important	Somewhat important	Very important	Critical
Basic research	1	6	27	65
Early applied research	1	2	18	78
Development	0	7	29	63
Demonstrating technologies in a relevant environment	0	11	33	56
Deployment in pilot lines	1	14	33	41
Full deployment – early adopter	2	15	28	46
Number of respondents	104	104	104	104

Source: CSTI survey of manufacturing researchers 2015

A striking result is the very small number of respondents (sometimes no respondents) that believe that involvement in any of the stages can be excluded.

When the responses to critical are categorised by the respondents' collaboration composition, it can be seen that a greater portion of academics involved in industrially dominated collaborations believe that middle stages are important to be involved in. This breakdown also indicates that all compositions have a greater portion of respondents saying that early applied research is critical to ensuring that the UK could benefit commercially from their collaboration's outputs.

TABLE 32: HOW IMPORTANT RESPONDENTS BELIEVED IT WAS TO BE INVOLVED IN PARTICULAR STAGES OF INNOVATION/ COMMERCIALISATION PATHWAY FOR THE UK TO BENEFIT FROM THE COMMERCIAL APPLICATION OF THE RESEARCH

Critical to be involved in:	IMRCs	Share of respondents that believe it is critical by partner composition:		
		Academic dominated	Balanced	Industry dominated
Basic research	65	65	71	56
Early applied research	78	78	74	85
Development	63	65	54	74
Demonstrating technologies in a relevant environment	56	48	54	70
Deployment in pilot lines	41	35	40	52
Full deployment – early adopter	46	40	51	48
Number of respondents	104	40	35	27

Source: CSTI survey of manufacturing researchers 2015

Ensuring the funded proposals deliver sufficient benefits to the UK

Ideally, an international collaboration is entered into by parties that see mutual benefit in conducting such a collaboration. Furthermore, politicians, civil servants, and agency personnel often have an interest in seeing these benefits captured within their own state's borders. Participants in the expert workshop were asked to identify the factors that would change the balance of the win-win situation in collaborations away from realising these benefits in the UK.

Benefit was defined in the workshop as national economic value capture, and excluded other social or political benefits (e.g. education, trade, foreign relations). This focus means that the findings apply to collaborations where value capture is an explicit goal of the funding organisation or programme and neglects other funding objectives (e.g. research excellence).

As with the rest of this chapter, uncertainty about economic value capture from research projects is an important consideration for funding programmes and significantly complicates assessments of potential value capture. However, participants still saw value in identifying general considerations that are often relevant when scrutinising proposals for funding for their national economic value capture potential. The core observations made by the workshop attendees that have implications for how funding proposals might be scrutinised include:

- **The value that might be captured nationally from IMRCs, which include understanding the different types of value created, the different value capture opportunities, the mechanisms for capturing value, and the ultimate contribution to the national economy** – participants discussed at length the different types of value that had been created by the IMRCs they had been involved in. Acknowledging the complex nature of economic value, they identified a number of aspects of value that needed to be understood when scrutinising proposals for their ability to capture value nationally (and comparing this to partner countries). These aspects included:

  - the type of value coming out of the collaboration (e.g., to products, processes, services)
  - where value capture opportunities are along the value chain
  - the mechanisms needed for value capture (e.g., IP/royalties, contract/in house production, consulting) and how it is configured into a business model
  - the ultimate possible value contribution to the national economy (e.g., high value jobs, productivity, tax receipts, company profits)

- **Variations in national attributes and infrastructure that influence whether value capture can happen within the UK** – participants also identified a number of national attributes and infrastructure important for national value capture, many of which were covered in the survey (see Table 30) including national absorptive capacity, skills, and regulation. However, participants also identified non-labour input costs, in particular energy costs, as another attribute about the UK that may play a role in value not being captured in the UK. Interestingly, energy costs were not mentioned in the comments that accompanied participants' responses shown in Table 30.
- **Requirements for value capture that are intrinsic to the specific research and its application** – participants identified a number of requirements for (often significant) value capture to be realised that could only be identified in specific value capture opportunities. These included the time to deployment (value generation and capture) and scale of deployment. These have implications on the type of companies that might pursue these value opportunities and their associated markets.
- **Whether the attributes of the firms that might absorb and deploy the outputs from the collaborations are important for value capture in the UK** – participants also recognised that in a number of situations the attributes of firms that might take up the research influence the ability to create and capture value, and do so within the UK. Such characteristics identified as relevant in particular circumstances included whether firms are foreign owned or not and whether they have the critical size to effectively deploy the research.

Also important for scrutinising research proposals for national value capture potential is how the above four observations interact. Participants discussed the alignment between the various considerations of value and national attributes. They also discussed the relationship between the requirements for value capture and the attributes of firms in the UK. This led to the identification of issues related to the **interdependence** of these observations and their related **dynamics**. These are illustrated in the following two examples provided by participants:

- When speed to market is essential for national value capture but patents are the main mechanism, tensions may occur because of the (sometimes lengthy) time involve in reaching the patent-related agreements needed for commercialisation (interdependence)
- Patents may be important mechanism for value capture early, but might become less important as markets become large and other competing products come online (dynamics)

Workshop participants believed these considerations where important when attempting to address the question of whether the possible *national* returns from funding a research project are *proportional* to the investment being made in the project compared to the investments being made by, and potential benefits for, *partner nations*.

10. Making international manufacturing research collaborations work

Key points from this section

The survey and expert roundtable workshop highlighted the following as key to making international manufacturing research collaborations work:

- Getting the right people is key. This can be a big challenge and is hampered by increasingly difficult immigration and visa regulations and costs. More could also be done by the international agencies to support this process although they need appropriate technical knowledge for this support to be effective.
- Beyond technical skills, the capabilities of those involved to work collaboratively and to manage projects were seen as critical. The latter was viewed as a highly underrated yet critical skill and one that was hard to sufficiently resource in projects.
- Communication, both between partners and across technical areas was crucial, and particular difficulties emerge around establishing sufficiently secure communications and data transfer/storage infrastructure.
- Alignment of interests, objectives and capabilities as well as a mutuality of credit for delivering outcomes. Trust and a mutuality of respect were also crucial.
- Conditions attached to grants were seen as a particular barrier in the UK to the effective functioning of international collaborations in manufacturing research
- A number of university characteristics were seen as hampering collaborations including the lack of coordination between different parts of the administration support organisation, and the ability to appropriately negotiate intellectual property in manufacturing research projects.

In addition:

- Medium sized projects were more likely than large and small projects to view the human factors and project design, alignment and compatibility factors studied in the survey as enabling than hindering. There was less variation for institutional characteristics and funding related factors.

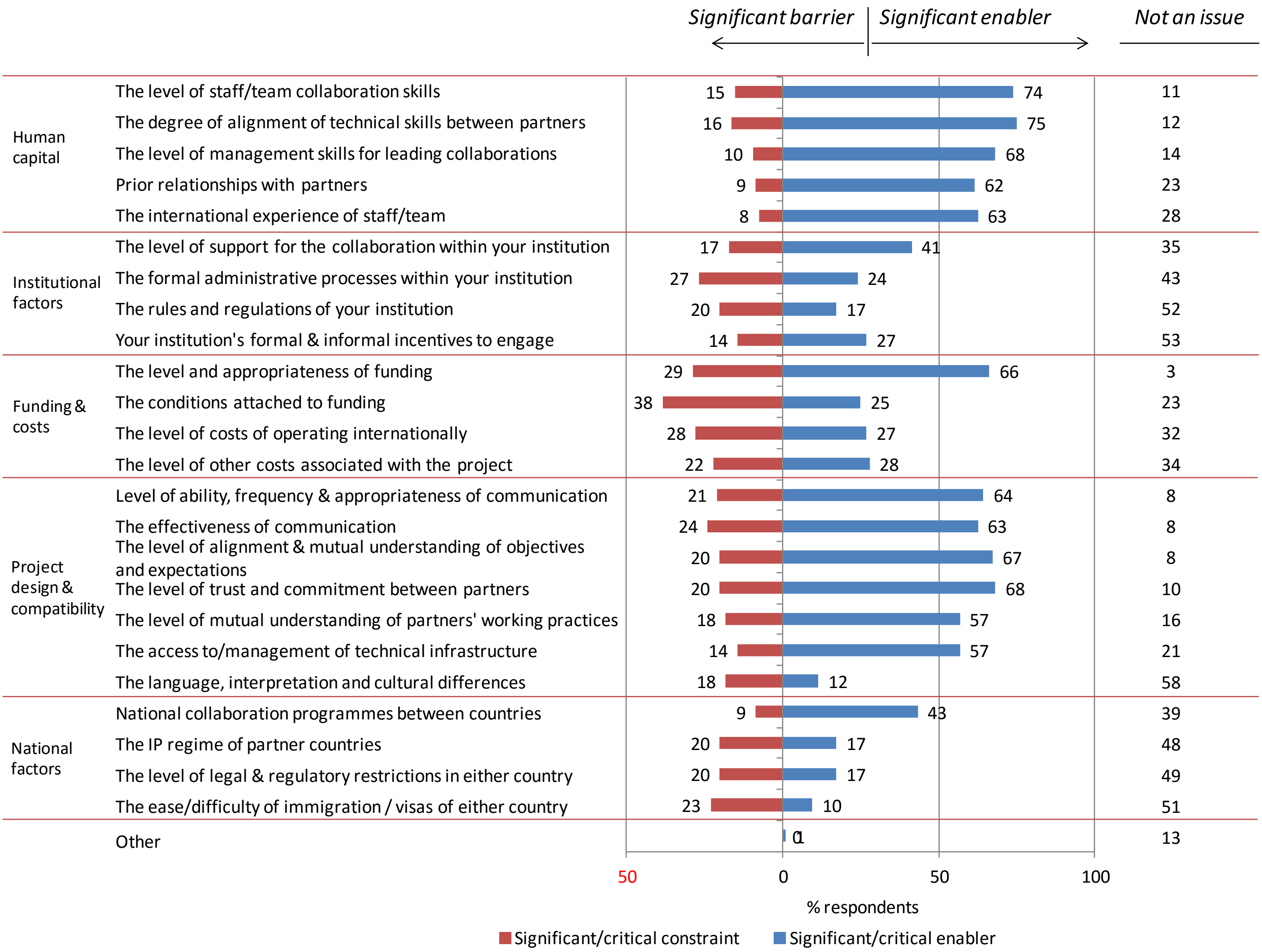
Many factors can influence the functioning of collaborations once set up. A review of the literature on the barriers and enablers to (international) research collaborations (Technopolis, 2005; Stokols et al., 2008; Casey, 2010; Sloan and Arrison, 2011; Bozeman and Boardman, 2014) and university-industry linkages (Bruneel et al., 2009; Hughes and Kitson, 2012) identifies a range of factors that can be broadly categorised into the following areas:

- **Human capital related** (including technical, managerial and team working skills, ability to work at geographic distance and across borders, prior relationships)
- **Institutional characteristics** (including the rules and regulations of the university, the amount of support provided for collaborations, and the incentives to engage in collaborations)

- **Funding and costs** (including the level and types of funding available, the conditions attached to grants, and costs of operating internationally)
- **Project design and compatibility** (including the alignment and mutual understanding of objectives and expectations; communication, trust and commitment between partners; understanding of each other's' working practices; and language and cultural differences)
- **National factors** (including national collaboration programmes between partnering countries; the IP regime; legal and regulatory restrictions; and immigration/visas)

The barriers and enablers to the functioning of IMRCs were examined both through the survey (Figure 13) and the expert workshop. The survey asked respondents to consider whether the identified factor acted as a significant or critical barrier or enabler for the operation of the project and its ability to realise its objectives.

FIGURE 13: ENABLING AND CONSTRAINING FACTORS FOR MAKING INTERNATIONAL MANUFACTURING RESEARCH COLLABORATIONS WORK



Source: CSTI survey of manufacturing researchers 2015

Skills

Most survey respondents identified factors relating to the skills and experiences of the collaboration team and those related to project design and compatibility as particularly important enablers for the functioning of IMRCs (Figure 13). In particular, the collaboration skills of the team and the degree of alignment of technical skills between partners were highlighted by approximately three quarters of respondents.

The expert workshop participants highlighted the need for a real desire and willingness to work together, with teams bringing complementary capabilities. A range of non-technical skills were required to make IMRCs effective including interpersonal skills and team building skills. They also argued that it was important to know when and how to rebalance teams should, for example, personalities involved begin to clash and cause difficulties. They also suggested that it was important, yet difficult, to be able to judge not just the technical competencies of the different IMRC team members across the different partners, but also the competence of the outputs produced in order to ensure that all partners are delivering quality.

People exchange was seen by workshop participants as an important element of effective IMRCs, not least for building trust and relationships, overcoming cultural sensitivities, fostering tacit knowledge flows etc. However, this was an element with particular challenges. One challenge involved the ability of enabling access within the manufacturing facilities of companies overseas to students making it harder to undertake effective research. The costs of moving internationally and the costs and challenges associated with immigration also made people exchange particularly challenge despite the perceived benefits.

Management skills for leading collaborations were also identified by 68% of respondents to the survey as a significant/critical enabler. This factor was also singled out by the expert workshop participants as a crucial, yet particularly underrated skill. Good project managers were seen as important not just for understanding the technology problem and ensuring the project is delivering on its objectives, but also for resolving 'off-plan' events. There was a consensus that this skill was not sufficiently rated in the UK. There were also important questions over whether – through peer pressure, anticipated funder reactions or other factors – academics were able to request sufficient funding for this type of function in project proposals.

The workshop also highlighted an important risk relating to the over dependence on specific individuals, particularly for larger, longer term collaborations. If project success is vested too much in a very small number of individuals, it risks collapsing should that individual leave. This is amplified when working with cultures where the relationships between people are seen as particularly important. Finding ways of creating multiple points of contact between different parts of the international project teams, while maintaining good and clear management and lines of responsibility, was seen as important.

Project design, alignment and compatibility

In terms of project alignment and compatibility, just over two-thirds of respondents to the survey highlighted the level of alignment and understanding of the project's objectives and expectations as an important enabling factor and a similar proportion identified the enabling effects of trust and commitment between partners. These factors were echoed in the expert workshop. Participants argued that trust – and integrity – was critical to the success of IMRCs. A mutuality of both respect between project partners and allocation of credit for achieving milestones and outcomes was important for delivering this trust. The workshop participants highlighted the benefits of explicitly including a period of face-to-face socialisation between project partners during the early days of the project to help build relationships, trust and a common understanding of each other's' cultures, working practices and constraints.

The participants identified a number of project management and governance factors considered important for the effective functioning of IMRCs. In addition to ensuring the project had good project management capabilities, it also required a clear and common understanding of objectives and milestones was important. There were also benefits from developing intermediate deliverables so that projects did not have to rely on final outputs to guide project direction and keeping the project on track. These could also act as a source of satisfaction for the partners. Other factors included regular review cycles of progress, minor course corrections to ensure the project remains on track, and a desire and determination to resolve problems between partners. Participants also highlighted the benefits – particularly for larger projects – of including a public relations and communications function within the project and that this was resourced. In addition to providing support for engagements into the wider public and industrial systems and the non-technical dissemination of findings, it could help to build a common culture and understanding within the dispersed project partners around achieving a common goal.

Communication was also seen as a particularly important enabling factor by those manufacturing researchers surveyed and by workshop participants. Interestingly, while the survey results suggested that language, interpretation and cultural differences were not seen as either an enabling or hindering factor by most IMRC academics, workshop participants argued that these differences (additionally including translation issues between disciplines) have the potential to create significant barriers to effective IMRCs. In addition, workshop participants noted the additional challenges of academics interacting with individuals on the 'factory floor' in countries where English is not a dominant language and where English is much less likely to be spoken. This was thought to be less of an issue when dealing with staff in R&D positions where some understanding of English is often required to engage fully with international research.

The importance of good and timely communication was also reinforced by workshop participants as an important enabling factor for successful IMRCs. They went further to note that, while email was a useful tool if projects were progressing smoothly and well, it could create difficulties and tensions if projects took a turn for the worse. In addition, they noted that video conferencing, while useful, was not a substitute for face-to-face meetings. There was a call for the need to improve communications between partners and individuals at all levels of projects.

The workshop participants also revealed an important challenge around the security of communications and data/document transfer and storage. Current provision was believed to be insufficiently secure and could hamper collaborations.

The uncertainty of investment decisions and how this affects the IMRC emerged in the workshop as a particular challenge when dealing with industrial partners. A number of experiences were recounted where decisions to close facilities important to the project were taken with little regard for the effect on the project. This caused significant disruption and in some cases termination of the projects.

Funding & costs

The level and of appropriateness funding was seen as an important factor influencing – either positively or negatively – IMRCs by most survey respondents. While two thirds viewed this factor as a significant enabler for their project, 29% perceived it to be an important barrier. In addition, 38% of respondents believed the conditions attached to the funding received acted as a significant or critical barrier to the project's operation and its ability to realise its objectives.

Discussions in the workshop revealed a number of further challenges within the UK funding landscape. The first concern was that the UK was spreading its funding too thinly to achieve critical mass in key areas. This, they believed, was hampering the ability of the UK to compete effectively on the world stage. Secondly, there was potential for conflict between the interests of the individual academics involved and the potential for national value capture potential to UK plc. These can be difficult to assess but need to be explored. Finally, the workshop highlighted occasions when the desire to access overseas funding or achieve other (non-scientific) socio-economic or political goals (e.g. trade, foreign relations) led either to a disproportionate allocation of benefits to the partner countries, or to researchers pursuing research with partners in those locations based non-scientific criteria (e.g. access to funding rather than access to best researchers for that challenge).

Institutional characteristics

Only just over a quarter viewed the formal administrative processes within their institution as a constraining factor. However, a similar proportion also viewed their institutions as aiding their ability to work internationally and 43% did not view it as having any effect.

The expert workshop identified a number of specific institutional challenges experienced by academics in developing IMRCs. Firstly, a high turnover of support staff within both universities and industrial partners led to additional costs (e.g. in lost time) in developing and nurturing the partnership. Each time someone leaves, the partners have to become acquainted with the new member of staff who may have different approaches, knowledge of the issues and capabilities. Secondly, workshop participants also complained of bureaucracy being too high to both initiate and manage IMRCs. Experiences highlighted the lack of coordination between the different parts of the university administration (e.g. finance, human relations, research contracts and knowledge exchange support) with different offices not talking to each other. The coordination function ends up being placed on the shoulders of the researcher which takes away time for research. Where identified, good and professional support and departmental managers were viewed as incredibly beneficial to the functioning of IMRCs.

National landscape and factors

Figure 13 also reveals that, in terms of national factors, while nearly half of the researchers viewed national collaboration programmes between partner countries as a key enabler, a quarter viewed immigration and visa issues as a key constraining factor (compared to just 10% seeing this as an enabling factor).

The expert workshop reinforced the growing challenges to IMRCs relating to the costs and difficulties surrounding immigration and the movement of people between countries. Participants argued that it was becoming harder to recruit the right people in a timely fashion to projects because of visa restrictions or rising immigration costs. These costs went beyond the visa-related costs but now included payments required of migrating researchers (and their families) to access public healthcare provision in the UK. In addition, they suggested that this was not just a non-EU problem, citing caps being imposed by the research councils on non-UK resident (including from the EU) students on projects. The workshop discussions highlighted the importance of people exchanges and mobility programmes generally in creating the conditions for collaboration, in terms of mutual understanding and prior relationships and trust.

In addition to the growing challenges and costs of immigration, workshop participants also identified regulatory issues, not least around international traffic in arms regulations (ITARs) and export controls. These provide significant restrictions on what can be done within IMRCs and often have relevance for manufacturing research and its potential applications.

Variations in barriers and enablers by project type

Important variations emerge when the survey results are broken down by different types of IMRCs. Table 33 presents the barriers and enablers for projects categorised by scale into small (<£250,000 per year), medium (£250,000 < £1,000,000 per year) and large (>£1,000,000 per year). Interestingly many project design & compatibility factors appear to be more frequently cited by medium-sized projects as enablers compared to small and large projects. In addition, medium sized projects were more likely to see the current level of management skills as a significant enabler compared with other sizes of project. There appeared to be less significant variation in the institutional characteristics and funding-related factors influencing IMRC functioning, where differences between project scales are, for the most part, relatively small.

Prior relationships were seen as an important enabler in almost three quarters of small projects while 44% of these sized projects (compared with 32% of medium sized projects) found the conditions attached to funding as a key constraining factor (although the latter was not statistically significant).

In addition, the data tentatively suggests an important trend in the challenges surrounding travelling between countries due to immigration difficulties, with a third of large projects citing this as a key barrier. However, due to the small sample size, this variation was not found to be statistically significant.

The study also examined the barriers and enablers for projects with different balances of academic and industrial partners (Table 34). The following highlights emerge:

- Collaboration skills of the team and prior relationships are increasingly seen as important enabling factors as the degree of industrial involvement in projects increases.
- The international experience of team members appears to be less important as an enabler by those projects dominated by industry partners.
- While many more industry-dominated projects found the level of support for collaboration within the university was a significant enabler compared with academic dominated and balanced projects, this variation was not statistically significant. The formal administrative processes within universities were more likely to be seen as a significant barrier by projects dominated a one type of partner (either industry or academic).
- The level & appropriateness of funding was viewed as a significant enabling factor in over 80% of industry-dominated projects. By contrast, half of academic-dominated projects found the conditions attached to funding as a key constraining factor. Interestingly this decreased as the relative share of industrial partners grows
- The level of trust and commitment between partners was much more frequently cited as a constraining factor for projects that had a mix of academic and industrial partners.

TABLE 33: ENABLING AND CONSTRAINING FACTORS FOR MAKING IMRCS WORK, BY FINANCIAL SCALE OF PROJECTS (% RESPONDENTS FOR EACH GROUP)

Factor		Significant/critical enabler			Sig.[a]	Significant/critical constraint			Sig.[a]
		Small	Medium	Large		Small	Medium	Large	
Human capital	The level of staff/team collaboration skills	69	79	70		17	12	17	
	The degree of alignment of technical skills between partners	69	85	70		14	9	23	
	The level of management skills for leading collaborations	58	79	67	*	8	9	13	
	Prior relationships with partners (e.g. alumni, prior projects, personal networks)	72	53	53	†	11	3	13	
	The international experience of staff/team	61	62	63		3	3	13	
Institutional factors	The level of support for the collaboration within your institution	39	38	47		14	15	23	
	The formal administrative processes within your institution	22	29	23		25	24	33	
	The rules and regulations of your institution	19	12	20		19	15	27	
	Your institution's formal & informal incentives to engage	22	35	20	†	14	12	17	
Funding & costs	The level and appropriateness of funding	61	68	67		31	26	30	
	The conditions attached to funding	28	24	23		44	32	37	
	The level of costs of operating internationally (e.g. travel, exchange rates, communication)	31	18	33		33	24	30	
	The level of other costs associated with the project	33	18	37		14	29	27	
Project design & compatibility	The level of alignment & mutual understanding of objectives and expectations	61	79	57	*	22	9	30	
	The effectiveness of communication (e.g. degree, quality, medium of communication)	56	71	57		25	18	30	
	The level of all partners' ability, frequency & appropriateness of communication	67	76	43	*	17	12	37	*
	The level of trust and commitment between partners	58	82	60	*	25	9	27	
	The level of mutual understanding of partners' working practices	44	65	57	*	25	12	17	
	The access to/management of technical infrastructure	47	62	60		14	12	17	
	The language, interpretation and cultural differences	14	6	17		19	15	20	
National factors	National collaboration programmes between countries	42	38	47		3	15	7	*
	The IP regime of partner countries	19	12	23		25	21	13	
	The level of legal & regulatory restrictions in either country	17	18	20		22	18	20	
	The ease/difficulty of immigration / visas of either country	14	6	10		17	24	33	
Other		3	0	0		0	0	0	
Number of respondents		36	34	30		36	34	30	

Source: CSTI survey of manufacturing researchers 2015

TABLE 34: ENABLING AND CONSTRAINING FACTORS FOR MAKING IMRCS WORK, BY PARTNER COMPOSITION (% RESPONDENTS FOR EACH GROUP)

Factor		Significant/critical enabler			Sig.[a]	Significant/critical constraint			Sig.[a]
		Ac. Dom.	Balance	Ind. Dom.		Ac. Dom.	Balance	Ind. Dom.	
Human capital	The level of staff/team collaboration skills	63	79	83	†	13	15	17	
	The degree of alignment of technical skills between partners	71	79	76		16	18	14	
	The level of management skills for leading collaborations	63	79	66		11	9	7	
	Prior relationships with partners (e.g. alumni, prior projects, personal networks)	50	68	72		11	6	3	
	The international experience of staff/team	66	71	52	†	5	9	7	
Institutional factors	The level of support for the collaboration within your institution	39	35	52		18	12	21	
	The formal administrative processes within your institution	32	18	24		29	21	31	†
	The rules and regulations of your institution	21	18	14		11	21	31	
	Your institution's formal & informal incentives to engage	32	24	28		16	12	14	
Funding & costs	The level and appropriateness of funding	61	62	83	†	29	32	21	
	The conditions attached to funding	29	24	21		50	38	24	*
	The level of costs of operating internationally (e.g. travel, exchange rates, communication)	34	26	21		26	35	21	
	The level of other costs associated with the project	37	35	7	**	24	21	21	
Project design & compatibility	The level of alignment & mutual understanding of objectives and expectations	63	74	69		18	12	31	†
	The effectiveness of communication (e.g. degree, quality, medium of communication)	63	59	69		18	29	24	
	The level of all partners' ability, frequency & appropriateness of communication	66	62	69		16	24	24	
	The level of trust and commitment between partners	66	68	72		11	32	17	*
	The level of mutual understanding of partners' working practices	61	56	55		11	18	28	
	The access to/management of technical infrastructure	58	65	48		13	12	14	
	The language, interpretation and cultural differences	11	15	10		18	21	14	
National factors	National collaboration programmes between countries	47	47	34		5	15	3	
	The IP regime of partner countries	21	15	17		21	21	17	
	The level of legal & regulatory restrictions in either country	18	15	17		18	24	17	
	The ease/difficulty of immigration / visas of either country	16	3	7	†	29	26	10	
Other		3	0	0		0	0	0	
Number of respondents		38	34	29		38	34	29	

Source: CSTI survey of manufacturing researchers 2015

TABLE 35: ENABLING AND CONSTRAINING FACTORS FOR MAKING IMRCS WORK, BY FUNDING SOURCE (% RESPONDENTS FOR EACH GROUP)

Factor		Significant/critical enabler					Significant/critical constraint				
		Public funded	Minor industry	Major industry	Other	Sig.[a]	Public funded	Minor industry	Major industry	Other	Sig.[a]
Human capital	The level of staff/team collaboration skills	76	87	61	68		12	27	28	5	†
	The degree of alignment of technical skills between partners	82	80	56	68	†	8	33	22	16	*
	The level of management skills for leading collaborations	70	80	61	63		12	7	11	5	
	Prior relationships with partners (e.g. alumni, prior projects, personal networks)	60	73	50	63		8	0	17	5	
	The international experience of staff/team	74	47	44	63	*	4	7	22	5	*
Inst. factors	The level of support for the collaboration within your institution	36	67	33	37		12	20	22	26	
	The formal administrative processes within your institution	24	20	22	26		24	33	28	32	
	The rules and regulations of your institution	16	7	22	26		18	27	28	16	
	Your institution's formal & informal incentives to engage	20	33	33	32		6	27	22	21	†
Funding & costs	The level and appropriateness of funding	66	87	50	63		22	33	39	32	
	The conditions attached to funding	26	20	28	26		36	33	50	37	
	The level of costs of operating internationally (e.g. travel, exchange rates, communication)	32	27	17	21		26	13	22	42	
	The level of other costs associated with the project	34	27	17	26		18	7	22	42	*
Project design & comp.	The level of alignment & mutual understanding of objectives and expectations	66	80	67	68		16	20	28	21	
	The effectiveness of communication (e.g. degree, quality, medium of communication)	58	93	50	63	*	20	13	39	32	
	The level of all partners' ability, frequency & appropriateness of communication	58	93	50	74	**	22	7	28	26	
	The level of trust and commitment between partners	68	93	56	58	*	22	7	28	16	
	The level of mutual understanding of partners' working practices	56	73	56	53		14	13	28	21	
	The access to/management of technical infrastructure	56	53	61	58		18	7	17	11	
	The language, interpretation and cultural differences	10	7	22	11		18	7	22	26	
National factors	National collaboration programmes between countries	38	33	44	68	†	8	20	6	5	
	The IP regime of partner countries	20	0	28	16		18	27	11	32	
	The level of legal & regulatory restrictions in either country	20	0	22	21		22	27	17	16	
	The ease/difficulty of immigration / visas of either country	4	0	22	21	**	26	20	11	32	
Other		0	0	0	5		0	0	0	0	
Number of respondents		50	15	18	19		50	15	18	19	

Source: CSTI survey of manufacturing researchers 2015

Lastly, the project explored variations in the barriers and enablers to the functioning of IMRCs between projects that were publicly funded and those with significant contributions from industry (Table 35). Key insights include:

- The level of staff and team collaboration was seen as a barrier for just over a quarter of IMRC projects involving industry funding, compared with just 12% of those funded through public sources
- Projects largely funded through public sources were more likely than those with significant industry funding to see the degree of alignment of technical skills as an important enabler
- The international experiences of the team were seen by 74% of publicly funded projects as a significant enablers compared to 44% of projects with significant industry funding. Indeed, the latter were much more likely to see the current level of international experience as a barrier to the functioning of these collaborations
- The level of a university's formal and informal incentives were much more likely to be seen as a barrier to international collaborations by those projects with some or significant industry funding involved. This perhaps reflects the ongoing challenges of incentivising academics to work with industrial partners more widely than just in international collaborations.
- The level of trust and commitment was seen as a significant enabler in most publicly funded projects with some industry funding (although not by those projects where industry funding is a significant source). The same was true of the strength of communication between partners.
- Very few respondents with projects funded solely or largely through public sources saw the immigration system as a significant enabler of their international collaborations. This compares with over a fifth seeing it as having constrained their ability to realise their project's objectives.

11. Challenges for initiating international collaborations in manufacturing research

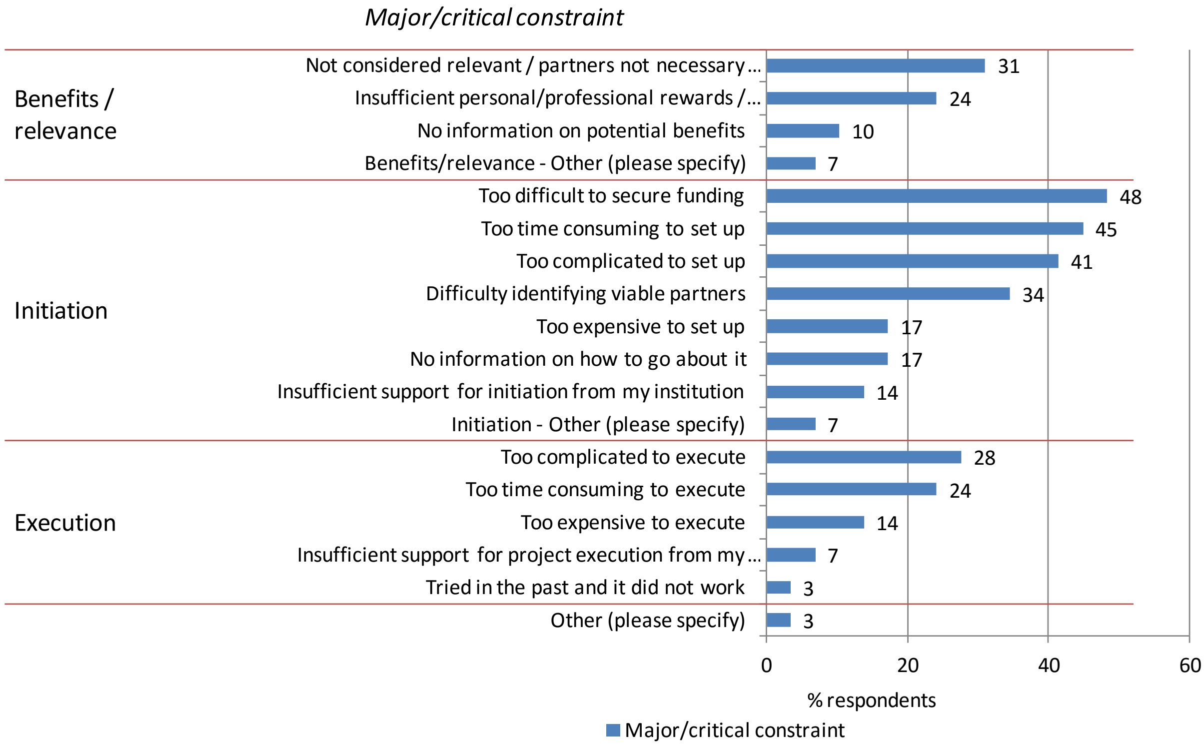
Key points from this section

- Many of those that did not engage in international collaborations in the survey viewed them as being too difficult, time consuming and complicated to set up; had difficulties in identifying partners, and did not view them as relevant or necessary to achieve their research goals.
- The expert workshop isolated a range of other factors that help or hinder the initiation of international manufacturing research collaborations, including:
    - The ability to identify partners with emphasis placed on prior relationships and professional and personal networks. The support received from key UK agencies located overseas in finding partners was reported to be mixed with some suggesting that the technical knowledge of the staff involved was insufficient
    - The cost of research in the UK was argued to make it harder to secure international partners
    - Anticipated costs and challenges around immigration and visas can act to prevent collaborations starting in the first place
    - University bureaucracy, administration and disagreements over intellectual property can hamper the formation of international collaborations. In addition the disciplinary structure of many universities can make it hard to put in place the necessary multidisciplinary collaborations often required in manufacturing research.
    - Academic culture and the pressures to publish in high impact journals can disincentivise academics from engaging in international collaborative research and in manufacturing research more widely

Approximately 30% of the respondents to the survey did not engage in international manufacturing research collaborations. This presented an opportunity to explore why these academics chose not to engage (Figure 14). Acknowledging the relatively small sample of those that have not engaged, this figure begins to reveal some insights into why. Many of the challenges centre around initiating IMRCs, with almost half of these respondents noting that it was too difficult to secure funding for IMRCs and 45% arguing that they were too time consuming to set up. Just over 40% said they were too complicated to set up while 34% said it was too difficult to identify partners.

Some also cited challenges with project execution that put them off even pursuing IMRCs, including being too complicated or time consuming. In addition, 31% did not consider IMRCs as relevant to their research or partners were not necessary, while 24% saw insufficient personal or professional rewards and incentives.

Figure 14: Factors affecting decision not to engage in international manufacturing research collaborations



Source: CSTI survey of manufacturing researchers 2015

The expert workshop examined the barriers and enablers to initiating IMRCs, including both the identification of partners and their set up. Key areas included: challenges around identifying partners; costs of operating internationally and availability of funding; issues around bureaucracy, intellectual property and negotiations; and the incentives and culture rewarding international engagements in manufacturing research.

Identifying partners

A key challenge in initiating any international collaboration in research is identifying the right partners. Given the highly specific nature of many research projects, it is frequently the case that individuals with the necessary set of expertise and competencies (and access to the right resources and facilities) to address the research challenge will be not be based local to that academic and potentially not even be located in the UK. There was a general consensus that it was hard to understand, at a sufficiently granular level who is doing what, in both academia and industry. This adds to the significant challenges of identifying the viable and valuable partners. In addition to identifying people with the right skills, that partner has to be willing to work with the academic adding another important dimension and challenge to finding the right partner.

Identifying potential partners is facilitated through prior relationships and academics' professional social networks. Other technical and specialist academic and academic/industry networks can also play an important facilitation role for identifying potential partners. However, becoming a trusted member of these networks can be difficult leading to additional challenges for identifying partners.

However, while the benefits of prior relationships and social networks was readily acknowledged in the workshop for making it easier to identify partners, there was also a recognition that these could lead to 'lock-in' and 'blinckeredness' where existing partners are prioritised over potentially valuable new partners. This is in part driven by the importance of trust and personal relationships for making collaborations work leading to potentially significant hidden costs for establishing new partnerships (e.g. in the time necessary to develop trusting relationships). In addition, negative past experiences can have important effects on the potential for future collaborations and potentially lock-out academics from important networks for some time.

The UK government also funds the internationally based Science and Innovation Network, a network of 90 staff based in 28 countries (47 cities) around the world. These individuals work with the local science and innovation community to support UK policy goals. In addition the UK Research Councils have teams based in key partner locations including the US, China, India and Europe. The workshop revealed that a key challenge for these organisations in facilitating IMRCs is being able to operate at a sufficiently granular and technical level to be able to help a UK researcher identify a specific target for collaboration (either in academia or industry) (or vice versa, helping an academic or industry partner overseas find a specific academic in the UK). Experiences at the workshop were mixed on the ability of the Science and Innovation Network to deliver here, with some participants arguing that support was too general in technical knowledge to help identify viable partners while others were happy with their capabilities. Experiences were similarly mixed with the capabilities of other internationally focused trade and investment agencies in being able to help researchers identify specific and viable partners for their collaborations.

The challenge of identifying partners for IMRCs has also been made more difficult as a result of the decline of major corporate R&D labs. These provided both a natural cohort of industrial partners that were easily identifiable for academics. Absent of these labs it has become much harder to identify the 'right person' within industry with which to partner.

There is also the challenge of enabling potential partners to find, access and partner with, UK academics. This was seen as particularly difficult for SMEs who find it hard to identify who within a university, or even which universities, to approach. Workshop participants cited the existence of the variety and breadth of Fraunhofer Institutes in Germany with clear and specific missions that make it much easier for SMEs to identify where to go to address a particular technical challenge.

The UK does, however, benefit significantly from its international reputation for research excellence at the forefront of the scientific and technological frontier. It also benefits from having a venture capital base that is willing to invest in university-originated technologies. This makes it much easier to find partners who are willing to partner with UK academics than would be the case if the reputation was lacking.

Some participants also argued that the setting of high-level strategic R&D priorities can provide a useful focal point around which collaborations can coalesce. However, this could be a double-edged sword if funding is diverted to these core challenges and researchers find themselves working outside these priority areas.

Lastly, workshop participants noted the importance of the UK's strategic international linkages (for example with the European Union) in facilitating the formation of international collaborations that reflect the UK's priorities and strengths.

Costs & funding availability

The anticipated costs of IMRCs can also hinder them starting in the first place. Some participants argued that the cost of overheads in the UK made research expensive and less attractive to overseas partners. Others, however, countered this cost barrier could be overcome through the targeted use of funding programmes to provide important leverage for other partners. Costs associated with access to specialist national facilities such as the national supercomputing service (ARCHER) and some facilities funded by the Science and Technology Facilities Council were also identified as creating potential cost-related challenges for IMRCs.

There was a consensus on the challenges associated with the rising costs of getting the right people involved on IMRCs. This included in particular those associated with immigration and visas, but also included associated costs being imposed on foreigners working in the UK such as additional contributions to access healthcare (in addition to the contributions already being made through their tax bill).

The lack of funding and resources in partner organisations (particularly in SMEs) to support international collaborative manufacturing research was also seen as a challenge. These types of industrial partners also find it difficult to understand a potential value proposition from these collaborations with their needs often misaligned (both in focus and timescale) with the research activity.

The availability of funding in foreign partner locations may also be misaligned to UK funding priorities making leverage of each other's' capabilities, competencies and resources harder to achieve in these specific areas.

That said, trends towards challenge-led funding and long-term commitments to strategic research areas made it much easier – if researchers are active in these spaces – to invest the effort in building related IMRCs.

University structures, bureaucracy and intellectual property

The workshop identified a number of challenges faced by researchers related to university structures, bureaucracy and negotiation over intellectual property.

The types of challenges inherent in manufacturing research typically stretch well beyond the traditional disciplinary boundaries upon which universities are often structured. The challenges of forming collaborations across disciplines even within a single university are well known and this can make it much harder to assemble the right set of partners to address manufacturing-related challenges (which often benefit particularly from multi-disciplinary approaches).

In addition, a number of challenges were identified relating to university administration, not least the lack of motivation and ambition of personnel to take the time to understand the potential long term value of (in particular large scale) international collaborations. This made it much harder for academics to secure the necessary buy-in at the institutional level to move collaborations forward. In addition there accusations that many university administrators were not willing to negotiate on overheads based on case specifics.

Another area where challenges were identified to the initiation of IMRCs was around the negotiation of intellectual property, and the confidentiality and sensitivity of some manufacturing research. Participants argued that the nature of manufacturing research meant that patentable IP was often generated and hence the ability to protect and exploit IP became particularly important for the commercialisation of the research outputs. The oft-cited concerns around university IP offices being overprotective of IP or unrealistic over IP terms were inevitably raised with claims that this can end up preventing the research collaboration from starting up. However there were also claims that industrial partners can also be unrealistic around their expectations over IP and conditions to be attached to research contracts with academics.

There were also issues around the sensitivity and confidentiality of information that needed to be shared to make some manufacturing research collaborations work. This can make it much harder to setup up valuable collaborations. The ability to develop appropriately secure infrastructure and contracts to enable this to happen was seen as a challenge.

Lastly, people exchange is often argued to be important for making collaborations successful. A big problem faced by collaborations involving industrial partners can arise over requests by the latter for universities to provide unlimited (or incredibly high) insurance liabilities for their staff working on their campuses.

Incentives and culture

Challenges around the incentives and culture within universities to encourage international manufacturing research collaborations were raised by workshop participants. Manufacturing research in general was cited as lacking high-impact journals as traditionally measured and accepted by the wider (non-manufacturing) academic cohort. Academics motivated by achieving tenure can thus be dis-incentivised to engage in the more applied research activity often required to address manufacturing challenges.

The workshop participants also noted that UK academics were not proactive in establishing and leading international collaborations. This could lead to UK academics working on research and technology priorities that are set by other countries and may be less well aligned to UK interests.

12. Discussion and conclusions

There is growing recognition of the importance of manufacturing research in driving industrial competitiveness (O'Sullivan, 2011). Governments are therefore concerned that the research they fund in this area is delivering value to their national economy. International collaborations are believed to valuable, for example, to address critical mass research and innovation challenges, and ensure that the UK has access to the necessary capabilities and resources to address these.

The report highlights the geographic breadth of international collaborations in manufacturing research (IMRCs) involving UK academics, the many and varied reasons why international partners are brought into these collaborations, and the barriers and enablers to making them work. In addition it reveals the range of anticipated direct technology-based and wider (non-technology) effects of the research outputs from these collaborations in their journeys towards impacts. The primary purpose of the project was to provide a stronger evidence base in this area for government departments and agencies. However, the findings are likely to be of value to universities looking to strengthen their ability to engage internationally in research, to academics building international research teams, and to other research actors in the innovation system. In addition, while the project focused on manufacturing research, many of the findings are likely to be relevant for other research areas although further work would be needed to confirm this.

Manufacturing research is not easily isolated as a separate research domain. It spans a broad range of science and engineering disciplines, from applied science and technology (including device physics, applied chemistry, materials science and biotechnology); to physical production engineering; to decision system engineering as applied to manufacturing industries. Some also argue it should stretch further to include research on management, innovation, skills and policy as applied to manufacturing challenges. The following statements bring together some of the core concepts made by the academic manufacturing research community (identified by those funded through the EPSRC manufacturing the future research portfolio) when asked to define manufacturing research:

- Manufacturing research focuses on addressing needs and issues related to the manufacture of new and existing products, and with attention to efficiency, sustainability, and the economics of production (frequently focusing on new product development and deployment).
- Manufacturing research encompasses theories & methods for the definition, synthesis, analysis and simulation of engineered products, processes and services
- Manufacturing research expands to consider more than just the firm-level manufacturing system including the supply, distribution and support network for the engineered products, processes and services

Despite the difficulty in defining the domain the survey respondents claimed that manufacturing research is key to enabling technology-based concepts emerging from basic research to be scaled-up, and commercially deployed in the marketplace and deliver economic and social impacts.

The international collaborations that form within manufacturing research have different structural characteristics. They range from small (less than £250,000 per year) to very large (more than £1 million per year); from a few partners to many; from academic-dominated to industry-dominated (based on the proportion of each type of partner in the total); and from solely publicly funded to involving significant industrial funding. The report reveals that these characteristics are associated with different types of activities and barriers/enablers to making them work.

Where in the world?

The survey revealed the geographic footprint of international partners involved in IMRCs. There is a spread of countries involved in IMRCs with UK academics although a number of key hotspots emerge. The most frequent locations in which academics partners are situated are Germany, France, the US and Italy. However, the distribution narrows significantly when one focuses on key partner locations for realising project objectives. Noticeably Italy drops out of the top four locations for academic partners with the Rest of Europe taking its place. For industrial partners, the locations cited most frequently for having partners mirror relatively closely the academic partner locations (Germany, US, Italy and Netherlands). However, when looking at the most important locations, Spain emerges as a key location (alongside Germany, US and Italy). These correlate closely with key large advanced economies with strong high value manufacturing bases, and countries that are geographically proximate or with strong historical, cultural and (for the US) linguistic ties.

What was perhaps surprising from the survey was that a number of locations including China, India, Ireland and Australia & New Zealand, while relatively frequently cited as a location for academic and industrial partners, were rarely cited as particularly important for realising project objectives. This is particularly striking in the case of China which is the UK's second most frequent source of co-authors in manufacturing research publications. This suggests that collaborations are developed for more than just generating publications, or other mechanisms are more effective or appropriate for building international relationships for co-authoring publications.

The limited number of hotspots of key academic and industrial partners suggests these countries are both consistently strategically important and academics are able to form relationships with potential partners in these locations. This also suggests that the 'long tail' of other locations are either not strategically important, or are difficult to access, or both.

Why involve international partners?

Given that most of the IMRCs identified in the survey listed the EPSRC and EU framework programmes – with their focus on funding the earlier phases of the research endeavour – as major funders, it is unsurprising that partners from most locations were brought on board for their research expertise and know-how. Also important was the ability of partners to access funding, and to access highly specialised facilities (for both academics and industrial partners). Other frequently cited motivations included established relationships, manufacturing expertise and know-how and access to large scale facilities. A wide range of other factors were important in selected cases (creating a long tail of other factors in aggregate). Also interesting is that factors were more concentrated for involving academic partners than for industrial partners.

Interestingly, few statistically significant differences emerge when looking at the factors for involving partners from different locations. While a number of these variations are not statistically significant, the results tentatively suggest that partners are brought into collaborations from different locations for different reasons, although these findings would need further work to confirm. This includes involving German academic partners for their access to highly specialised facilities (closely followed by UK partners); US academic partners for their deployment know-how; and partners in developing East, South East and South Asian economies for their access to large-scale facilities (again UK partners are almost as frequently brought into collaborations for this reason). As expected, and reinforced by the expert workshop, established relationships play a big role in choice of partner across all partner locations.

Where industry is a major funder of IMRCs, academic partners are more frequently involved in IMRCs for their commercialisation expertise and for their market/industry intelligence than in collaborations funded through other sources. This highlights some of the types of capabilities and knowledge of academics that are valued in major industry-funded projects which are in addition to those valued in solely or largely publicly funded projects. This raises an important question as to whether *and* when these types of capabilities might add value to the latter types of manufacturing research projects.

The relatively low frequency of bringing industrial partners in publicly funded or major industry funded projects suggests that these projects are not tackling research with significant scale or risks challenges that require collaboration. It is the publicly funded projects with some industry funding where these types of research challenges are being addressed. Instead publicly funded or major industry funded projects are included industrial partners for many other reasons (see Table 17) or are tackling large scale or high risk projects that do not require industrial inputs in the collaboration.

What are the partners doing in international manufacturing research collaborations?

A key focus for IMRCs is on advancing knowledge through stages of the innovation process with relatively less effort placed on addressing the wider innovation activities supporting the development and deployment of these technologies (e.g. management practices, seeding industrial clusters and policy). Indeed, within the stages of the innovation process, activities stretch well beyond basic/fundamental research into addressing research challenges at higher stages of the technology readiness levels (TRLs) including activities in the development and technology demonstration phases). This strong focus of these IMRCs on the stages of innovation reveals that much less attention is being given to issues outside the core technology development, including the infrastructure required to support and deploy that development. This raises an important question about who supports these wider activities and whether this low focus within *international* collaborations is desirable or not for UK value capture.

The survey also reveals that, as IMRCs become more dominated by industrial partners (based on partner composition), industrial partners pay more attention to issues further along the innovation process, although perhaps less than one might expect. However, and critically, there was no evidence that they significantly reduce their emphasis on basic/fundamental research. Academics pay similar attention to these later stages of the R&D process regardless of the composition of the collaboration.

What are the anticipated direct effects from international manufacturing research collaborations?

International manufacturing research collaborations are an important mechanism for advancing the underpinning science and engineering research base, and developing the enabling tools and techniques, for technology-driven R&D. Fewer collaborations anticipate direct contributions to platform technologies and even fewer to applications in products, processes and services. This is in-line with the cohort that was studied (the funded academic research community of the EPSRC Manufacturing the Future portfolio). Other cohorts of academics and researchers funded outside the MtF portfolio (e.g. Innovate UK or the UK government's Newton Fund) would have different compositions of anticipated direct effects more aligned to the objectives of those funding programmes.

The IMRCs are making wider, non-technology contributions, including developing technical, manufacturing and management skills, and to new product development practices and protocols. These contributions are in-line with the desired objectives of the EPSRC MtF portfolio and are important for facilitating technology deployment in practice to generate economic value, including in the UK.

What are the key challenges to exploiting research outputs in the UK?

As observed in chapter 9 of this report, the most important factors for enabling the UK to realise economic and social benefits from the research outputs emerging from manufacturing research collaborations include the capacity, capability and willingness of the UK industrial base to absorb, adopt and deploy technologies and processes emerging from UK research.

Another very frequently cited factor was the availability of factory-like facilities in the UK. This is perhaps a bit surprising given that few partners (UK-based or overseas) are brought into the collaborations for their access to large-scale facilities. A potential explanation may lie in that while such facilities are important for the exploitation of research outputs here in the UK, it has moved beyond the point where academics themselves are involved in the process. Nevertheless, UK academics involved in IMRCs believe that the UK currently has a relative strength in such facilities for testing and demonstrating technologies. In other countries these types of facilities have been found to be provided by intermediate technology and innovation institutes as well as through large scale investments co-located on university campuses.

Following these factors, the availability and quality of research and manufacturing skills in the UK are seen as important for the ability of the nation to exploit and capture value from the research outputs. The surveyed researchers also perceived these areas to be an area of relative strength for the UK.

The current level and focus of public investment is also seen as important as was the coordination of public support from one stage of development to the next was seen as important for exploitation. These were areas where survey respondents found the UK to be particularly weak.

Table 31 also highlights that UK researchers involved in IMRCs identified early applied research that advances concept emerging from basic research as critical to capturing value from manufacturing research in the UK.

What makes international manufacturing research collaborations work?

A wide range of human and relational factors, factors relating to project design, alignment and compatibility, funding and costs, institutional characteristics, and the wider national system influence the effective functioning of IMRCs. The following were found to be important in the survey and the expert workshop:

- **Getting the right people involved is crucial; however, key challenges exist around identifying partners, specific people to involve, and immigration.** A big challenge surrounds how to identify the right individuals and the subsequent difficulties and costs associated with immigration and securing visas for the right to work in, and travel to, the UK. Individuals had to have the right technical skills as well as an interest in collaborating with the UK academics. Given the highly specific nature of research challenges, these individuals are often based outside the UK.
- **Good project management is crucial; however, this was a skill that is underrated in the UK.** In particular it was found to be hard to adequately resource in project proposals. Regular review cycles and reviews of the strategic and technical direction of projects were also seen as important to ensure that they remain on track to deliver valuable outcomes and make mid-course corrections. In addition, collaboration skills, trust, and ability to communicate between partners were viewed as core capabilities necessary to make collaborations work. With respect to communication, difficulties emerged around establishing sufficiently robust and secure communication, data transfer and storage infrastructure.
- **Collaborations need to deliver benefits to all sides involved.** Effort needs to be invested in ensuring an alignment and understanding of each other's' needs and objectives and establishing clear and common objectives. In addition, there needs to be mutuality of credit for delivering outcomes as well as of respect between partners (i.e. partners need to be seen as equals).
- **The funding landscape could be strengthened** to further support international manufacturing research collaborations. Survey respondents highlighted particular challenges around the conditions attached to funding grants, while workshop participants argued that there was a lack of critical mass funding in key areas to enable the UK to take leadership positions in global collaborations.
- **A range of institutional (university) factors can impede the effective functioning of these types of collaborations.** In particular, the organisation of universities around traditional disciplines makes it much harder to develop collaborations in manufacturing which are inherently interdisciplinary. The incentives facing academics also act against pursuing highly multi-disciplinary research that is inherently applied in nature. The high turnover of staff in key university administrative functions can also create additional challenges to the effective functioning of these collaborations as does the lack of a coordination between different parts of the administration (e.g. finance, human resources, research contracts etc.).

Wider observations

The survey found a relatively high consistency of involvement of both academic and industrial partners in similar project activities, particularly in the earlier phases of the research process. This is despite differences in the roles of firms and universities in innovation processes that are often articulated. In addition the survey also revealed that, beyond research expertise and know-how, academic and industrial partners are brought into collaborations for quite different reasons, yet they perform remarkably similar activities regardless of project type. This suggests that different and diverse perspectives from academic and industrial partners are being brought to bear on the particular activities required to address a given research challenge.

It is clear from the survey that some IMRCs focus primarily on early stages of the innovation process (TRLs 1-2) and make significant contributions to the advancement of the underpinning science and engineering base that will be hopefully subsequently lead to the development of technologies that will be deployed in the marketplace. However, many projects stretch well beyond these early TRL stages with both industry *and* academic partners involved in activities in the latter stages as well as activities outside the TRL chain that are inevitably important for delivering impacts. This indicates that addressing manufacturing research challenges often requires undertaking research activities well beyond TRL1-3 which could either be an indicator that this type of research is different to other domains, or points to issues with using the TRL scale as a framework to determine where the public sector should invest or not. Either way, it raises important questions about the efficacy of using the TRL scale in determining the role of the public sector in supporting manufacturing research.

Given that both academic and industrial partners focus their project activities on the earlier stages of the R&D process, it is perhaps unsurprising that many of the direct anticipated effects of research emanating from IMRCs are within the science & engineering research base (as well as on measurement and testing tools and modelling and simulation). More surprising, however, are the anticipated effects on the development of technical and manufacturing skills, and new product development practices and protocols given that few projects give much attention to activity in the latter stages of the innovation chain (higher technology readiness levels). If the perceptions of academics about their anticipated effects are realised, this suggests that, through wider activities supporting the development and deployment of the technology, they are able to have direct effects on novel products, processes and services without having to focus too heavily on latter stages of *technology* deployment. It reinforces the view that a simple focus on the different stages of the innovation chain will not capture the full set of ways through which collaborative academic-industry research can have impact. The results have found contributions to a variety of enabling factors underpinning technology deployment are important for creating and capturing value in the UK. This may have implications for how collaborative proposals (in particular their pathways to impact) are assessed.

In conclusion, the study unpacks the geographic landscape of international collaborations in manufacturing research involving UK academics. Involving partners in projects is driven by their research expertise and know-how regardless of where in the world they are based. However, beyond this, partners based in different locations provide access to different types of resources, expertise and competencies to address manufacturing challenges. The study also highlights the wide range of contributions to different types of technology development as well as wider contributions to the development and deployment of these technologies. This suggests that simple analyses of contributions of research to different technology readiness levels may miss the important variety of technologies and wider innovation activities necessary to deploy the core technology. Finally, the study revealed that while Germany, France and the US were frequently cited as key partner locations, surprisingly few academics viewed China, India and other emerging economies as critical for realising their project objectives. However, while there might be significant future opportunities for collaborations with these locations, their value should be assessed with respect to the UK's national economic, social and political interests. Additional effort may be required to stimulate and support academic collaborations in manufacturing research with these locations where they offer significant value opportunities for the UK.

Lastly, international manufacturing research collaborations will have greater leveraged resources, better access to equipment and facilities (both specialised and large-scale) and access to expertise and know-how that are not available nationally that will enable them to address key manufacturing challenges of importance and economic value to the UK.

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