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Introduction

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4 KEY QUESTION: What balance should we strike between meeting capital requirements at the individual research project and institution level, relative to the need for large-scale investments at national and international levels? (1000 words maximum)

Answer to question 1:
The UK should adopt a three pronged approach, dividing its capital investments into three approximately equal and ring fenced sub-funds, to ensure the availability of adequate resources on a continuing basis to underpin:
a) global pre-eminence in curiosity driven and fundamental research
b) continuity of participation in long-term international collaborations (e.g. space)
c) campaigns to apply and exploit ground breaking new science and technologies as they emerge (e.g. graphene)
The UK needs to plan for both project and institutional investment which helps to translate scientific discovery into national benefits in a timely manner. Responsive mode funding which is available at present is not, in the main, strategically 'joined up'. Adopting more of a challenge-led, 'road map' based approach (although complex to achieve and implement) is the most effective way to enable a strategically joined up investment approach to be implemented for the long-term. Approaches currently employed by the MRC and EPSRC reveal some good examples of how this can be achieved. Adopting a challenge-led approach is also beneficial. It can connect various otherwise individual projects at a range of Technology Readiness Level (TRLs), supporting enhanced exploitation between academia and industry. Britain's research and technology organisations (RTOs) play a key role in such multi-disciplinary collaborations and can stimulate new more fundamental research projects by linking researchers to challenges in the field. Societal challenges such as 'efficient resource use' or 'resilience' are good examples – requiring a mix of multi-disciplinary engineering and more fundamental science.
At the same time a reasonable proportion of the total funding should continue to be made available for individual academics to underpin a critical mass of 'blue skies' research.
Strategic decision making bodies have to prioritise over 10 year or longer timescales to ensure continuity of participation in international programmes which enable the UK to remain a global player in major scientific and engineering advances e.g. at CERN and in Europe's Space Programmes. A particular issue in planning commitments for UK participation in such large international programmes is the need to factor in allowance for fluctuations in currency exchange rates and to avoid 'raiding' funds intended for national programmes when rates move against the UK.
Likewise, some headroom needs to be provided to enable the UK to respond to application opportunities which need investment in capital infrastructure in order to embed new scientific advances and technologies within the innovation ecosystem, both within and beyond the universities. Priorities in this area need to be responsive to signs of emerging potential and uptake within industrial and commercial applications. Investment capacity needs to be managed to ensure that the UK has the ability to follow up with development of the application infrastructure without undue delay. Decisions around such emerging, near term opportunities need to be made on a case by case basis, in the context of:
• the relative strengths and weaknesses of the UK's innovation infrastructure (i.e. existing national capabilities and expertise mean that inevitably the UK is better positioned to respond and perform with regard to opportunities in aerospace, transport, agri-food, pharmaceuticals and other priority industry sectors;
• the case for return on investment (both short-term and long-term);
• the potential for societal and humanitarian impact;
• the capacity of the UK to bring emerging technologies to market and compete;
Overall, this means balancing the long-term need for the UK to remain committed in international collaborations and fundamental science with the imperative of obtaining an economic and societal return on investment. This balance should reflect the fact that the costs of developing, engineering and exploiting technology in most instances far outweigh the costs of the initial research, but recognising also that beyond the capital infrastructure needed to support exploitation, private sector interests should be able to finance much of the applications work required.
The capital infrastructure needs for these application activities extend beyond the universities across the entire research and innovation sector. Given the breadth of requirement for capital investment through most of the stages of encompassed by the TRL stages, it seems clear significant prioritisation will be necessary in terms of which industry sectors, applications and emerging technologies to support. The BIS industrial and 'great' technologies strategies are therefore to be welcomed. Without such concentration on key areas it is inevitable that resources will become too thinly spread and disjointed to provide an effective return on investment.
The rationale for suggesting three approximately equal categories of international, basic research and application capital spending is that
a) the international programmes deliver attractive incentives for people to take up careers in science and technology and the develop advanced engineering skills and capabilities that have widespread application;
b) fundamental science is a UK strength and provides early sight and a knowledge base in advances that may have a major impact in the future;
c) applications of new advances in a sustained and well-coordinated manner is crucial for the UK's economic prosperity and for generating the returns needed to pay for investment in the categories above and for continuing application development. The infrastructure needed to underpin such applications requires

equipment and facilities for independent testing, validation, accreditation and demonstration of new technologies and systems.
It is hard to see that any one of the three categories should be less generously funded than the others without risking damage to the continuity and capabilities needed for UK scientific and economic success in research and innovation.

5 How can we maximise collaboration, equipment sharing, and access to industry to ensure we make the most of this investment? (1000 words maximum)

Answer to question 2:
A portfolio management approach should be deployed to invest capital across the priority areas that the UK has already committed to in recent years (i.e. those in the BIS industrial strategy and the 'Eight Great Technologies'). As part of this, opportunities for collaboration, equipment sharing, and industrial involvement should be core to the strategy for each area of investment.

Placing equipment and facilities, particularly those needed for development, testing and demonstration, should be concentrated on those organisations and establishments having large, established industry networks and the business processes that develop such networks. This is a key feature of RTOs and IROs which, alongside the Catapults, rely on such networks to deliver their services and goals. Data being obtained from a current study of the innovation sector by Oxford Economics shows IROs to be particularly well connected to industry in this manner. The Knowledge Transfer Networks should also be used to bring their networks into play to facilitate collaborations in key technology areas.

Placing in RTOs and IROs will encourage collaboration through usage with universities and will assist in the transfer of knowledge and expertise to a wider industry base than can be reached from the university on its own, as is the case with the Catapults, but on a larger scale since more organisations will be brought into play.

Nevertheless, equipment and facilities sharing can be a complex business in terms of scheduling access to fit with project timelines and other factors. It is not cheap to arrange and may involve buying time from shared staff as well as access to the facilities. This can raise questions of confidentiality and additional cost. The concept works best for the most expensive equipment and facilities where the administrative cost is a small fraction of the capital and other running costs. Sharing arrangements are probably best built into the stipulated conditions under which the capital grant is offered up front, with some assistance also being given for support to administration costs.

It is important to consider carefully where advice on the portfolio management of investments is coming from. Peer Review is not always necessarily the best approach. The UK should look to models of portfolio management which have assembled skill sets based on experience and know-how (not merely representation of a relevant community). It is essential to incorporate transparency into the process. Sourcing expertise from the business community should be core to the Government's investment strategy. Business expertise can assist in managing uncertainty and help ensure the UK remains globally competitive. Measures should always be put in place to ensure that vested interested (potentially both academic and private/commercial) do not dominate decision making processes.

6 What factors should we consider when determining the research capital requirement of the higher education estate? (1000 words maximum)

Answer to question 3:
Maintaining a strong higher education estate is essential to the future global competitiveness of UK plc. It should be understood that meeting requirements for research capital investment has the potential to support the long-term strength of the UK's skills base in science and technology, as well as delivering scientific discoveries and potential innovations of important economic significance. The right facilities, if provision is made to ensure they are well sustained and utilised, should be considered key to the development of advanced research skills to help the UK to remain globally competitive.

Consequently, as well as considering the equipment needs of the research itself, the capital budget for the HE estate should support the delivery of outcomes to business and industry in terms of access both to the equipment and the provision of graduates and postgraduates with knowledge of the equipment and facilities base and of the research that can be undertaken using it.

Examples of good-practice that model collaboration between HEIs and other organisations with mid-TRL level capabilities should be replicated. For example, Brunel University and TWI have collaborated (with other key academic institutions also) to establish a Structural Integrity Research Centre using HEFCE funding. This provides research facilities, alongside important post-graduate training opportunities, that extend beyond the Technology Readiness Levels (TRLs) of 1-3 usually provided for in a purely academic environment and right across levels 4-7. This is arguably a way for the UK to get a better return on investment by developing postgraduates with a broader and more commercially applicable skill set. RTOs and public sector research establishments (PSREs) are well placed to partner with Universities to achieve this.

7 Should - subject to state aids and other considerations - science and research capital be extended to Research and Technology Organisations and Independent Research Organisations when there are wider benefits for doing so? (1000 words maximum)

Answer to question 4:
In addition to translation of expertise into the broader UK skills base (as described in question 6), investment in the mid-TRL capabilities that reside of the RTOs and IROs leads to other wider benefits. The principle is being demonstrated with the Catapult Centres. IROs in particular operate in a similar manner to the Catapult Centres but currently lack capital infrastructure on the scale available to the Catapults. Extending Capital budgets to include RTOs and IROs would extend the leverage and impact of these organisations and that being established by the Catapult network at a fairly modest cost.

Investing in this manner with RTOs and IROs will not simply result in investment in scientific development, testing and validation capabilities, but will also lay the foundation to support for process development and scale-up capabilities in business and industry, together with development of the requisite standards to underpin innovation. For example, for the UK to realise a return on investment in graphene research, it needs to develop quality testing methodologies for graphene in order to facilitate effective translation into products with commercial potential and impact.

Tackling the so-called ‘valley(s) of death’ is another important priority for the UK: the relative paucity of investment in early-stage technologies to carry them through the mid-TRL stages of development could be addressed by raising investor confidence in the UK’s capacity to innovate by providing increased capital investment in the infrastructure of the RTOs and IROs, enabling them to bolster national capabilities in key technology areas. Enhancing the UK’s infrastructure for mid-TRL activities is essential also for attracting inward investment in key areas such as aerospace, transport and life sciences etc.

The UK currently has an RTO/IRO and innovation sector that is more than twice the size of the Fraunhofer network in Germany, turning over more than £5.5Bn pa and employing over 40,000 scientists and technologists, mutli-skilled in innovation. (AIRTO estimates that this equates to the resources of approximately 20 research intensive universities).This represents a massive resource for the UK to further exploit where the available expertise matches the identified strategic technology gaps in the UK’s innovation landscape. Where there is clear economic benefit for strengthening the UK’s mid-TRL capabilities, the feasibility of expanding already successful established RTOs/IROs should be explored and pursued. Only if it is unfeasible to expand an already established organisation, should a new structure be formed from scratch.

The evolution of campuses as seed beds for innovation does not have to be centred only on universities. While this is a valid approach, and one the UK has deployed for many years, in some instances it may be easier to add real value by establishing facilities in and around RTO partners, seconding in academic staff for collaborative activities as appropriate. This model is currently being developed at NPL on the Teddington estate. Co-location with new or extended capabilities at an existing industrial site should also be considered e.g. by developing satellite sites linked to established RTOs. Such operational models can make the transition from lower TRLs to applied research and then to industrial application much easier, since there will already be a pre-existing critical mass of expertise and industrial development facilities on site, aiding operations, staff development and ongoing employment opportunities. Organisations adopting such models should be assigned a distinct identify and ownership relationship to RTOs . The new Structural Integrity Research Foundation at TWI in association with Brunel, Cambridge, and Manchester Universities –which leverages industry expertise - would be a good example of this approach. Other models of engagement include the BRE Innovation Park, NPL’s laboratory at the University of Huddersfield and MIRA’s Technology Innovation Park.

8 KEY QUESTION: What should be the UK's priorities for large scale capital investments in the national interest, including where appropriate collaborating in international projects? (1000 words maximum)

Answer to question 2:
The UK must prioritise those areas where it can build on existing investments and strengths. Largely the technology areas have already been outlined by the BIS Industrial Strategy. However there are also key global collaborations, particularly those with European involvement that should be prioritised e.g. the large hadron collider at CERN and some of Europe’s Space Programmes.

As discussed in questions 4 and 5, a portfolio management approach needs to be adopted to prioritise such investments effectively.

It should be noted that there appear to be a considerable number of mis-classifications in the appendices, which, if uncorrected, could mislead a high level overview of the content and purpose of the research infrastructure portfolio. For example, a number of the European Space Agency’s projects, such as Copernicus and Cryosat are aimed at understanding of our planet and ultimately at the provision of decision support information to governments and others. Similarly the TRUTHS mission falls into the same category. And Galileo is fundamental to the global positioning infrastructure on which much of business and industry depends. In a portfolio management approach it will be important to correctly classify such projects by purpose and potential contribution to impact on the economy and society.

Furthermore, rarely does industry appear as a delivery partner, and this would seem to be a missed opportunity for fostering business and industry engagement with the science base and UK research infrastructure.

9 What should the criteria for prioritising projects look like? (1000 words maximum)

Answer to question 6:
The criteria should comprise and take account of:
1. the quality of both the science to be undertaken and its impact on the UK’s international standing and the level of engineering development that UK suppliers could pick up in the procurement.
2. the relative strengths and weaknesses of the UK’s innovation infrastructure (i.e. existing national capabilities, skills and expertise mean that inevitably we are better positioned to respond and perform with regard to some opportunities is sectors such as space, agri-food, pharmaceuticals etc);
3. market demand for development of new products and services through scientific progress;
4. the case for return on investment (both short-term and long-term) reflected in wealth creation, job creation and economic impact;
5. the potential societal and humanitarian impact;
6. the capacity of the UK to compete in bringing resulting technologies to market (including the ability of the UK to attract private investment and the strength of the industrial base in a given sector);
7. the scope and arrangements for engaging with UK business and industry, both in exploiting the outcomes and in procuring the equipment and facilities required.
8. and, importantly, the quality of the project plan and the team managing it.
Clearly criteria 1 and 8 are the most important, followed by 4. Where the project is lacking content to give a good score in terms of the remaining criteria the proposal should be amended to bring up those scores.
I terms of international collaborations, opportunities to site facilities in the UK should be taken wherever possible.

10 Are there new potential high priority projects which are not identified in this document? (1000 word maximum)

Answer to question 7:
The UK must continually consider emerging global challenges in health, defence, climate change, energy security, aging population, supplies of food and water and population growth with regard to its investment in the science infrastructure. The capacity of the UK to respond swiftly to emergencies should be considered, as there are clearly important geo-political implications of being able to play a leading role in challenge led innovation. For example, the UK should maintain capacity by continuing to invest capital in its infectious disease research capabilities. International efforts to eradicate infectious diseases and tackle anti-biotic

resistance in human and animal health are key to the both UK's national health and role in international development. This includes multi-agency approaches that have received some investment from international governments, charitable and commercial sources e.g. tackling Malaria, West-Nile. Also, diseases that have the potential to cross the species barrier and be easily transmitted by international travel (e.g. avian influenza) should be tackled in order to mitigate their threats to global agricultural, health and economic stability.

11 Should we maintain a proportion of unallocated capital funding to respond to emerging priorities in the second half of this decade? (1000 word maximum)

Answer to question 8:
Yes. If the UK does not do this, it stands to miss out on important opportunities to play a leading international role in pioneering new technologies and markets, with the loss of economic benefit.

It should be noted that innovation in some sectors, such as IT, outstrips the pace of research in many aspects of the discipline. Clearly in such areas it is not possible to predict priorities out to 2020. Hence an appropriate proportion of capital funding should remain unallocated for the time being.

12 Are the major international projects identified in the consultation the right priorities for this scale of investment at the international level? Are there other opportunities for UK involvement in major global collaborations? (1000 words maximum)

Answer to question 9:
International investment is likely to be focussed on very high cost infrastructure that no one nation can provide on its own – hence these are largely big physics programmes. The potential benefits of joining up UK investments with their equivalent centres overseas should always be considered an option. For example, the proposed investment in big data to link genotype with phenotype will be well served by linkage with research centres across the globe. However for such programmes to show a good return on investment, particularly given the time taken for research to translate into long-term solutions, capital expenditure must be balanced with sufficient operational expenditure. If the UK is to make large infrastructural investments it is essential that these assets are heavily utilised, and that only occurs if adequate consideration is given to the source of operational expenditure as well.
In considering major international projects it is also important to achieve a good balance of projects that enable Britain to deploy its relative strengths in both science and engineering. At present, the projects identified in the consultation are weighted heavily towards using the UK's pure scientific capabilities. Engineering opportunities may exist in collaborations which focus on future cities for example. Significant business opportunity resides globally with large engineering projects supporting developing nations and there are a growing number of global thematic research clusters developing around these topics - the UK must be able to engage with these. This would require the extension of UK capabilities to ensure the outputs from research are state of the art. This particularly involves large infrastructure builds for the utilities (including civil nuclear energy) and transport and validation of structural methods, which require significant test and evaluation capabilities. The UKTI Large Value Opportunities programme seeks to identify those international projects which will ultimately offer significant UK business opportunities (>£250m), but they can also act as a catalyst for the exploitation of research outputs and the development of further research projects since many are 10+year programmes overall. This mechanism may act as a platform for developing links to overseas capabilities and other sources of leading edge research, at the same time connecting the UK science base to these clusters.
Another important task is to seek engagement with international projects designed to enable the public and private sector to join forces to tackle problems where there is a strong demand for innovation, but where a commercial market is still undeveloped. An example of this is the growing challenge of anti-biotic resistance. The increasing demand for new treatments for resistant infections is being heralded as a growing major threat to global health and prosperity. However the inherent need for carefully rationed use of any future new medicines emerging from R&D programmes limits the capacity to recover costs, and removes commercial incentive for industry to tackle the problem without public investment (including capital investment) being made. Through MRC investment in the last century, Britain rose to the challenge of tackling bacterial diseases and trail-blazed the discovery of penicillin and its translation into clinical practice, thereby transforming global human and animal health over subsequent decades; it is this kind of ambition and vision to apply science and engineering to global challenges that the UK must continue hold to maintain its position as a world-leading nation; provision must be made from capital budgets to support the necessary research and trials programmes.