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INNOVATION POLICY AND THE UNIVERSITY SYSTEM IN TIMES OF CRISIS AND RECOVERY:

WHAT WE KNOW AND WHAT IT MEANS

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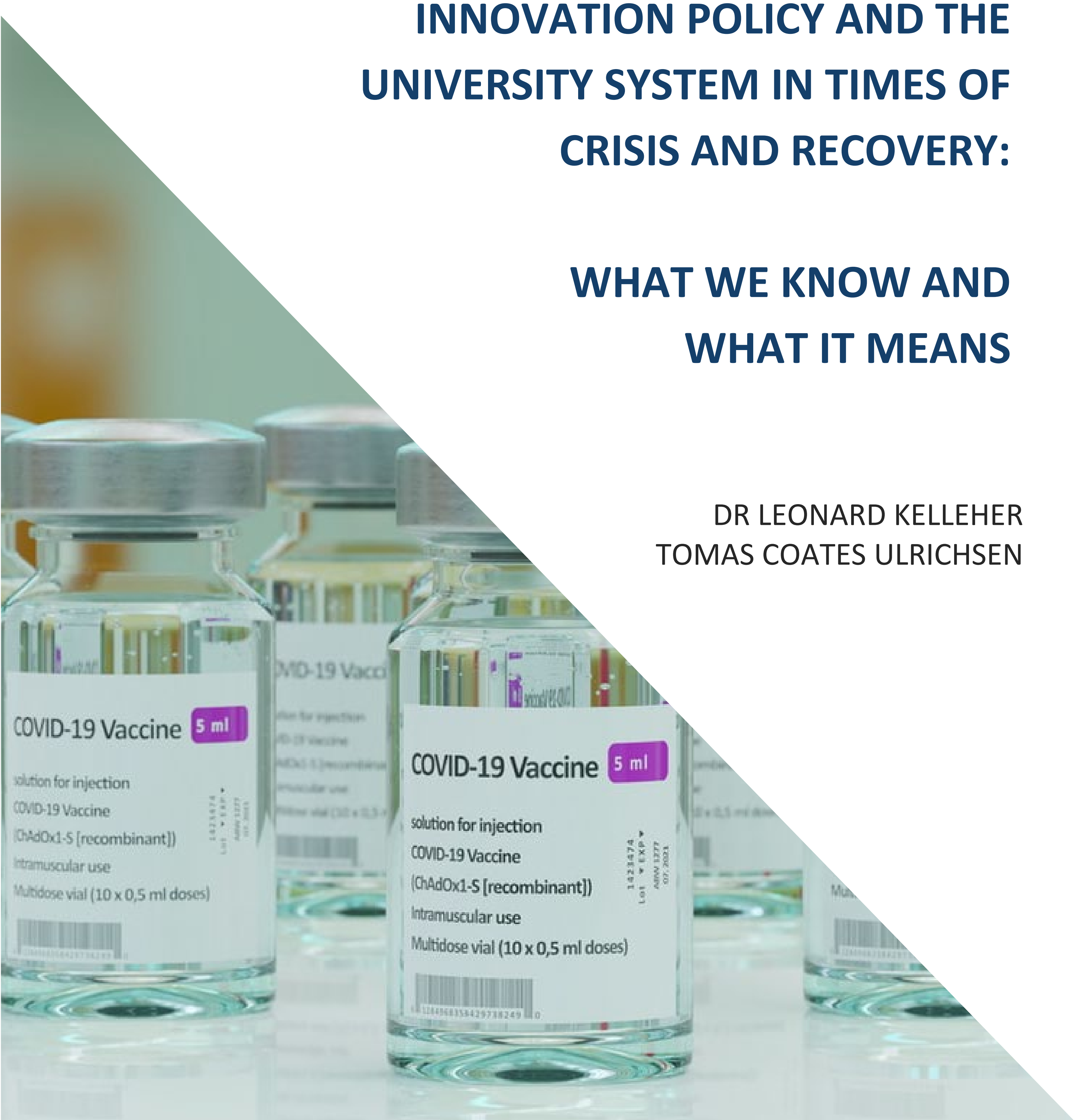

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ABOUT UCI

The University Commercialisation and Innovation Policy Evidence Unit (UCI) is based at the University of Cambridge and aims to support governments and university leaders in delivering a step change in the contributions universities make to innovation and economic prosperity – nationally and locally – through their commercialisation and other innovation-focused activities and partnerships.

UCI seeks to improve the evidence base and tools available to key decision makers in public policy and university practice as they develop new approaches for strengthening university research-to-innovation and commercialisation pathways. To do so it draws on the latest advances and insights from both academic research and policy practice, as well as lessons learned from experiences in the UK and internationally.

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Executive Summary

Executive summary

This report examines how innovation policies are changing: in the runup to the Covid-19 pandemic, through the immediate crisis phase, and into the economic recovery. We focus in particular on what these changes mean for the role and contributions of the nation's research base to driving an innovation-led recovery and the future competitiveness of nations. In doing so, we explore the various rationales for the public funding of universities during the crisis and into the recovery.

The report is based primarily on 'desk research', involving a review of literature on the rationale, role and focus of innovation policies and how these policies need to adapt through times of extreme crisis and post-crisis recovery, as well as emerging evidence on the impacts of the pandemic on innovation systems and the ability of actors in the system to innovate. We focus specifically on how these policies incentivise and engage the research base. To ground our review in reality, we explore the recent experiences of the United States and Germany in developing such policies, identifying examples of how they seek to strengthen their respective research bases within the innovation system.

Key themes identified within the report are summarised below.

Pre-pandemic innovation policy

Rationales used to justify government intervention in markets and innovation systems

Innovation for growth framework, addressing the following market failures:

- Information asymmetries
- Externalities, including knowledge spillovers
- Market power

Innovation systems framework, addressing the following system failures:

- Hard and soft institutional failures
- Hard and soft network (or complementarity) failures
- Lock-in failures
- Infrastructural failures
- Capability and learning failures
- Unbalanced exploration-exploitation mechanisms

Transformative change framework, addressing the following transformational system failures:

- Directionality failures
- Demand articulation failures
- Policy coordination failures
- Reflexivity failures

Example policy instruments supporting university-business interactions and research commercialisation justified by historic rationales	**Market failures** – public funding for basic and applied research; support for patenting and licencing; subsidies and incentives for private sector R&D and venture capital; tax incentives **System failures** – public funding from basic and applied research to development, deployment and diffusion; strengthening system linkages; public-private partnerships; large research infrastructures; support for new technology-based firms and academic technology transfer; multidisciplinary centres and programmes; networks & clusters; revision of laws, regulations, and standards; entrepreneurial culture building; technology foresight mechanisms; skills development; seed capital programmes **Transformative system failures** – direction-setting & maintenance mechanisms; joint learning processes; demand-side measures to stimulate innovation; tentative governance; strategic niche management; strategic intelligence; adaptive policy approaches; measures to support reflexivity.

Pandemic effects on innovation and innovation systems

Effects of the pandemic on innovation and key actors in innovation systems

Pre-pandemic innovation policy was predominantly reactive (addressing market and systems failures), but the pandemic has challenged this approach.

Effects of the pandemic on innovation and key innovation system actors include:

Public and charitable sector R&D investment

- Rapid global expansion of pandemic-related funding
- Higher levels of public R&D funding continuing into the economic recovery (in UK, US, EU, China)

Private sector R&D and investment

- Decreased productivity within UK firms
- Significant disruption to industry innovation strategies and decreased R&D investment across most sectors, which is expected to be prolonged
- Increased private sector R&D investment by some firms, leading to a concentration of innovative activities among a small group of firms
- Mixture of creative destruction (lower productivity firms being replaced by higher productivity firms in some sectors) and destruction (lower productivity firms being lost and not being replaced by higher productivity firms in others)
- Disruption of global supply chains

Research and innovation rate

- Rapid adoption of policy measures to mobilise innovation systems
- Subsequent responsiveness and agility of the system to enable rapid responses to COVID-related need)
- Increased rate of innovation
- Increased openness of science and innovation
- Expansion and disruption of international collaborations

Levels and focus of university-industry innovation partnerships

- Significant disruption to university-industry partnership activities and ability of universities to contribute to innovation

Research and innovation directionality

- High elasticity of science (researchers switching focus of their work to COVID-related issues)
- Insufficient anticipation of consequences of R&D and reflexivity concerning moral responsibilities to society within the innovation system
- Bias against funding high risk-high reward research
- Gravitation towards easier, lower-value and less promising inventions

Societal challenges

- New policy priorities to 'build back better'

Innovation during the pandemic

Differences between pre-pandemic innovation policy and crisis innovation policy

Innovating during crises differs from that in normal times in terms of:

- Large social returns on R&D investment
- Need to act quickly
- Objective shifts from non-specific, broad technological advance to crisis resolution.

Innovation policy during the pandemic emphasised interventions not justified by a market fixing approach, including:

- Prioritising applied research to address urgent problems
- Focusing on short-term results
- Coordinating research efforts and knowledge flows within innovation systems
- Funding overlapping and parallel R&D efforts
- Focusing on development, demonstration, and diffusion of innovations

Innovation during the recovery

Innovation policy for COVID economic recovery	Post-pandemic innovation policy is increasingly shifting away from reactive approaches to a more proactive 'systems transformation' approach, combining a focus on overcoming system failures with system transformative elements, including: • Enhanced anticipation of innovation's opportunities, challenges, spillover effects and consequences • Improved directionality through taking account of a broad range of views concerning possible development paths • Broadened inclusion in terms of both participation in innovation processes and a more equitable distribution of innovation benefits • Increased deliberation involving iterative exchanges of views, requiring enhancing societal capacities to understand, communicate on, and shape technological development • Responsible innovation through encouraging ethical, anticipatory and reflexive approaches from the private sector, particularly for emerging technologies.
Rationales for public funding for university innovation-focused activities during the recovery	Early evidence suggests that UK universities are adapting through the pandemic to meet the demands and opportunities of this more proactive innovation policy approach. Post-pandemic public 'recovery' funding could focus on enabling universities to: • Address ongoing and emerging COVID-related public health needs • Strategically adapt and pivot innovation-focused activities to meet the changed needs of economies and societies post-pandemic • Maintain their R&D and innovation capabilities and infrastructure through the crisis until demand for R&D, KE, and innovation activities recovers or new opportunities are unlocked, thereby enabling long-term growth.

Introduction

1 Introduction

In the summer of 2021, the UK unveiled its Innovation Strategy (BEIS, 2021), aimed at making the UK a global hub for innovation by 2035. The strategy recognises that innovation needs to be at the heart of the economic recovery from the COVID-19 pandemic, and includes ambitions to level up the economy and to drive the UK's future global competitiveness. It also positions innovation as central to addressing the biggest and most complex challenges the world currently faces, from climate change to ageing societies to future global pandemics.

As is typical with innovation policies around the world, the nation's research base – including amongst others, universities, research institutes, technology development and research translation and commercialisation-focused organisations – is positioned as important for delivering on ambitions. What is less clear from the strategy is where and how universities and other research organisations will play a role.

It is clear, though, that the world is changing around us and we are in a time of great turbulence compared with the pre-pandemic period. The economic impact of the COVID-19 pandemic is unprecedented in modern times (Harari and Keep, 2021), and governments have spent vast sums of money to mitigate the worst effects on the economy and the health of their citizens. This has led to very difficult fiscal climates in many countries.

While the immediate health crisis is starting to abate in some countries (although certainly not globally), governments are now beginning to look beyond the pandemic and are developing innovation policies to shape where, how and when to invest in innovation to drive recoveries and future long-term competitiveness.

In this report, we examine how the focus of innovation policies is changing and, in particular, what this means for the role and contributions of the nation's research base to innovation to drive the economic recovery from the pandemic and the future competitiveness of the nation.

In doing so, we review the latest academic literature on the rationale, role and focus of innovation policies and how these policies need to adapt through times of extreme crisis into recovery; explore what we know about how the pandemic has disrupted innovation systems; and look at what roles innovation policies suggest for universities. We look specifically at the recent experiences in the United States, Germany and the UK to provide examples of how innovation policies have been developing.

Overall, in relation to innovation policy and universities through the pandemic, our review suggests that public funding should be invested during the crisis period of the pandemic to help universities to:

- Prioritise applied research in response to urgent needs
- Focus on short-term results and knowledge diffusion from lab-to-application
- Coordinate research efforts and knowledge flows.

Further, as we move from crisis into post-pandemic recovery, we believe it is important that public funding is provided to enable universities to:

- Continue to respond to ongoing and urgent pandemic-related needs
- Adapt their strategic priorities to reflect potentially significant changes to innovation priorities and opportunities, and reconfigure their organisations to be able to pursue these new opportunities
- Maintain R&D and innovation capabilities and infrastructure through what is likely to be a prolonged recessionary period until demand for R&D, knowledge exchange, and innovation activities recovers or new opportunities are unlocked, thereby enabling long-term growth.

Pre-pandemic innovation policy

1 Pre-pandemic innovation policy

Question addressed in this section

- What rationales have historically justified government intervention in markets and innovation systems within pre-pandemic innovation policy?
- What types of policy instruments supporting university-business interactions and research commercialisation do these rationales suggest?
- What types of policy instruments relevant to the researc base did US and Germany innovation policies emphasize?

Summary of key findings:

- Three conceptual frameworks have informed innovation policy, each offering different rationales for government intervention (labelled ‘failures’):
    - Innovation for growth framework, addressing market failures
    - Innovation systems framework, addressing system failures
    - Transformative change framework, addressing transformational system failures.
- These frameworks offer different rationales that justify policy intervention, including:
    - Market failures – public funding for basic and applied research; support for patenting and licencing; subsidies and incentives for private sector R&D; venture capital; tax incentives
    - System failures – System failures – public funding from basic and applied research to development, deployment and diffusion; networks & clusters; revision of laws, regulations, and standards; entrepreneurial culture building; technology foresight mechanisms; large research infrastructures; support for new technology-based firms and academic technology transfer; multidisciplinary centres and programmes; skills development; public-private partnerships; seed capital programmes
    - Transformative system failures – direction-setting & maintenance; joint learning processes; demand-side measures to stimulate innovation; tentative governance; strategic niche management; strategic intelligence; adaptive policy approaches; measures to support reflexivity.
- Recent innovation policies in Germany and the US prioritised all three types of failure in their mix of policy instruments.

Innovation policies provide important frameworks for governments in shaping how they allocate resources to strengthen the innovation performance of their nations. In guiding the development of policy instruments, they also have an important influence on *how* a research base is mobilised to engage in the innovation process.

Governments justify innovation policies based on a number of different rationales detailing why, when and how interventions should be made in markets and innovation systems to increase the rate and value of innovation. Innovation policy has evolved over time as new conceptual frameworks gained influence. This has led to changes to our understanding of why government intervention in the innovation process is necessary, and how and where governments should invest.

In this section, we consider the evolution of frameworks for innovation policy, the types of market and system failures which they emphasise, and the policy instruments that are typically deployed.

1.1 Innovation for growth – addressing failures in 'perfect' markets

Historically, innovation policy was largely based upon an 'innovation for growth' framework (Schot and Steinmueller, 2018). This framework builds predominantly on traditional neoclassical economic theory and emphasises the importance of achieving a so-called 'perfect market equilibrium' (where all costs and benefits are fully reflected in market prices) for bringing about the optimal allocation of resources to maximise outcomes.

Within this framework, scientific knowledge is regarded as a key driver of technological change and, through this, economic growth. Economists have long argued that this type of knowledge has a number of characteristics that will lead to failures in the market and a consequential underinvestment in its production compared to what would be optimal for society. These include *uncertainty* (the impossibility of fully knowing the outcomes of research and associated risks), *inappropriability* (firms cannot fully appropriate the benefits which derive from their innovations due to externalities) and *indivisibility* (a minimum investment in knowledge is needed before new knowledge can be created) (Arrow, 1962; Nelson, 1959).

As a result of these characteristics, scientific knowledge is ultimately seen as a 'public good' that requires public investment to produce. A public good is one that is both *non-excludable* (i.e. once generated, it is hard to stop other people accessing it) and *non-rivalrous* (i.e. unlike a physical good such as a chocolate bar, multiple people can consume the same piece of knowledge at the same time).

Table 1 captures the key market failures which justify government intervention from the innovation for growth framework perspective.

Table 1| Examples of key market failures underpinning innovation policy (Arnold et al., 2014; Weber and Rohracher, 2012)

Failure	Description	Intervention
Information asymmetries	Innovation processes typically involve highly specialised technical and market knowledge. Differences in the information available to knowledge producers and users lead to power imbalance, suboptimal decisions, and precautionary behaviours (short time horizons, sub-optimal levels of private sector investment in knowledge development).	R&D funding & subsidies; tax incentives; measures to foster the availability of venture capital
Externalities	Arises when a company cannot capture the full benefits from innovation. This can arise when the technical characteristics of a good or service prevent property rights from being established or enforced, resulting in some of the benefits being realised by others. This can reduce the incentive to innovate and typically leads to private sector underinvestment in knowledge production compared to what would be seen as socially optimal. A common form of externality in this area is *knowledge spillovers*; as a result of the inappropriability of knowledge, organisations may benefit from the knowledge created by others without having to pay the market price for it. Spillovers can be generated, for example, by people moving between companies and reverse engineering. Not all externalities are negative. For example, in diffusing innovations the value of adopting an innovation will increase as the number of organisations using a technology increases (network externalities).	Funding for basic research; subsidy for private sector R&D and venture capital; patent protections
Market power	Refers to the ability of companies to extract 'rents' over and above the level of income that would have been available under 'perfect' competition. This could arise through, for example, companies exploiting economies of scale or scope, and the formation of monopolies within markets. Market power may increase the likelihood that a firm can capture benefits from innovation investments (positive effect), but too much market power can act as a break on innovation (negative effect), e.g. through building insurmountable barriers to entry for more innovative companies.	Price regulation, anti-trust/competition regulation

Most importantly from the perspective of universities, a market failure approach justifies measures such as public funding for basic and applied research, and support for patenting and licencing, as well as subsidies and incentives for private sector R&D and venture capital. The latter are important as weaknesses in R&D on the demand side can hamper the ability of firms to work with the research base to perform R&D and innovate, and commercialise novel technologies emerging from research. However, this approach provides little guidance on optimum levels of investment, what to invest in, or on the role of government in strengthening non-market interactions between knowledge producers and users (Chaminade and Edquist, 2010).

1.2 Innovation systems – strengthening the system to drive innovation

The past two decades has seen the 'national systems of innovation' framework become increasingly influential in innovation policy (Schot and Steinmueller, 2018). Drawing upon evolutionary economic theory, institutional economics and systems approaches, this framework sees innovation as a collective act involving interactions between different types of organisations (including large and small firms, universities, research institutes, investors, public sector agencies, and others) in development, deployment and diffusion of knowledge to drive innovation (Freeman, 1998; Lundvall, 1992). Behaviours within the system are shaped by sets of formal and informal institutions ('rules of the game'). Given the systemic and collective nature of innovation, both market-based and non-market interactions are critically important for effective knowledge flow between knowledge producers (such as universities and other research performing organisations in the public and private sectors) and those that will use it to drive innovation.

However, sub-optimal mechanisms and other barriers emerge within systems leading to *system failures* which weaken overall innovation performance (Table 2). These recognise the inherent difficulties in working across boundaries between organisations (such as universities and firms) that operate according to very different motivations and incentives, and are shaped by different institutions (social, political, legal, financial etc.). Since this framework for innovation policy took hold, policy instruments designed to strengthen the linkages between knowledge producers and users and to improve learning and coordination processes have become commonplace (Boekholt, 2010).

It is also important to note that proponents of the innovation systems framework for innovation policy see the idea of market equilibrium and perfect competition as unrealistic, and market failures as too narrow and misleading a basis for policy. That said, they still recognise the importance of the range of government interventions that are emphasised in the 'innovation for growth' framework such as science and R&D investments or capital markets improvements, albeit justified from a different theoretical standpoint (Dodgson et al., 2011).

For universities, system failure approaches to innovation policy have emphasised academic engagement to support partner organisations in meeting their innovation objectives, including technical problem solving, prototyping, demonstration and testing services, technology foresight services, access to specialist facilities, and network building. Services to strengthen innovation systems are also emphasised, including building entrepreneurial and workforce skills, supporting academic spinouts and start-ups, raising public understanding of new technologies, informing strategies for regional, technological or sectoral development.

Table 2| Key system failures underpinning innovation policy (Chaminade and Edquist, 2010; Weber and Rohracher, 2012; Woolthuis, Lankhuizen and Gilsing, 2005)

Failure	Description	Intervention
Institutional failures	Hard institutional failures include the absence, excess or shortcomings of formal institutions such as laws, regulations, and standards regarding IPR and investment. Soft institutional failures include barriers to knowledge flow caused by conflicts between competing cultural norms and values.	Revision of laws, regulations, and standards; use of incentives; funding conditionality; best practice sharing; public-private partnerships
Network failures	Hard network failures arise through overly strong linkages between actors, leading to a lack of infusion of new ideas, locking technological change into established trajectories. Soft network failures (or complementarity failures) arise through weak or missing network linkages which limit best practice diffusion, and hamper mutual learning and awareness of complementary knowledge and assets. These may be necessary to unlock the full functionality of an innovation, meaning potential positive effects may not be realised.	Innovation networks; clusters; enterprise zones; science parks; innovation districts; technology roadmapping
Lock-in failures	Organisations or regions may be excessively focussed on existing technologies and technological systems, with the system facing very large barriers to adopting new technologies[1]. Lock-in could be caused by a number of factors including very high upfront infrastructure costs associated with the adoption of a new technology, weak coordination between different organisations in the system required to deploy and diffuse a technology, and cultural aversion to change.	Technology foresight mechanisms; incentives, to develop technological alternatives, and to nurture emerging technological systems
Infrastructural failures	Absence of scientific, physical, and network infrastructure to increase coordination and learning within systems, due to large scale, long time horizon of operation and ultimately too low return on investment for private investors.	Large research infrastructures; competence centres; business incubators; seed capital programmes
Capability and learning failures	Lack of appropriate competencies and resources at actor and firm level prevent the access to new knowledge, and lead to an inability to adapt to changing circumstances, to open up novel opportunities, and to switch from an old to a new technological trajectory.	Workforce skills development; education; lifelong learning
Unbalanced exploration-exploitation mechanisms	Systems may lack either the capability to generate the diversity / variety of technological options (through creating new knowledge and ideas, exploration) or the ability to select from that diversity to pursue specific opportunities (exploitation).	Support for new technology-based firms

[1] Lock-in arises due to the existence of system externalities, combined with the fact that technologies cannot be separated from their social and economic environment (Smith, 2000). As such, technological alternatives must compete not only with components of an existing technology, but with the overall system (and its 'regime', consisting of a complex of scientific knowledge, engineering practices, process technologies, infrastructure, product characteristics, skills and procedures) which are exceptionally difficult to change in their entirety.

1.3 Transformative change – from reactive to proactive innovation policy

An emerging criticism of both the 'national systems of innovation' and 'innovation for growth' frameworks is that they are largely *reactive approaches* to innovation policy design (Chaminade, Lundvall and Haneef, 2018, pp.110–113); i.e. government interventions are developed after a failure has happened. Scholars are increasingly arguing that this type of reactive approach is proving ineffective and costly in addressing today's complex sociotechnical challenges, as has been demonstrated with the policy response to COVID-19 (Tonurist and Hanson, 2020).

A new proactive approach to innovation policymaking is emerging (Chaminade, Lundvall and Haneef, 2018, pp.113–115), which calls for much more emphasis on *anticipatory* and *action-oriented* government interventions to lead innovation activities along 'corridors of acceptable development paths' (Weber and Rohracher, 2012) in order to effect fundamental changes in models of production and consumption needed to prevent major societal threats or seize significant new opportunities.

This proactive approach is captured within a 'transformative change' framework for innovation policy (Schot and Steinmueller, 2018). This augments system failure arguments with a series of additional transformational failures associated with the long-term nature and broader scope of transformative change (Table 3).

A move to more transformative change approaches to innovation policy would see the research base becoming much more involved in, for example, efforts to help to: anticipate innovation's societal and ecological consequences (e.g. through technology assessment); address and encourage deliberation and reflexivity concerning the direction of research (e.g. informing development of mission-oriented innovation policy, engaging in breakthrough R&D, convening public dialogues on science and technology); and broaden participation in innovation processes and benefit sharing (e.g. through open innovation and place-based approaches).

Table 3| Key transformational failures underpinning innovation policy (Weber and Rohracher, 2012)

Failure	Description	Intervention
Directionality failures	• Lack of shared vision regarding the goal and direction of the transformation process; • Inability of collective coordination of distributed agents involved in shaping systemic change; • Insufficient regulation or standards to guide and consolidate the direction of change; • Lack of targeted funding for R&D and demonstration projects and infrastructures to establish corridors of acceptable development paths.	Direction-setting (technology-specific policies, technology roadmapping, mission-oriented innovation policies); maintaining direction during policy implementation (market creation and shaping, use of regulations & standards, funding demonstration infrastructures)
Demand articulation failures	• Insufficient spaces for anticipating and learning about user needs to enable the uptake of innovations by users; • Absence of orienting and stimulating signals from public demand; • Lack of demand-articulating competencies.	Support for joint learning processes involving producers and users ('living labs', strategic niche management, user-led innovation, open innovation); demand-side measures to stimulate innovation, (public procurement mechanisms, competency building among potential users)
Policy coordination failures	Concerns a lack of coordination across different levels and areas of policy relevant to transformative change: • Multi-level coordination across different levels of the system (e.g. regional–national–international, or between technological and sectoral systems); • Horizontal coordination between science, technology & innovation policies and sectoral policies; • Vertical coordination between ministries and implementing agencies resulting in deviation between policy strategic intentions and implementation; • Lack of coherence between public policies and private sector institutions; • Insufficient temporal coordination, leading to mismatched timing of interventions.	Tentative governance (dynamic processes to manage interdependencies and contingencies in a non-finalising way); strategic niche management
Reflexivity failures	• Insufficient ability of the system to monitor, anticipate and involve actors in processes of self-governance; • Lack of distributed reflexive arrangements to connect different discursive spheres, provide spaces for experimentation and learning; • No adaptive policy portfolios to keep options open and allow parallel developments to deal with uncertainty.	Strategic intelligence (evidence-based monitoring, anticipation, evaluation and impact assessment systems); reflexive arrangements when preparing transformative change policies (informal societal discourses, formal stakeholder consultations); adaptive policy approaches

1.4 Innovation policy and the research base in practice: the experiences of the United States and Germany

In practice, the design of national innovation policies, the mix of policy instruments, and the role of the research base within it, emerges from a complex political process which takes account of different national traditions, forms of state-market-society relations, the ideology of the government and socioeconomic priorities (Borrás and Edquist, 2013).

Nonetheless, two overarching trends may be discerned across the innovation policies of different countries. The first is that the 'innovation system' perspective has become increasingly influential in policy design over the last two decades (Dodgson et al., 2011). Recognising the inherent difficulties in working across boundaries, this has included an erosion of certain dualisms accepted within the linear model of innovation (Balconi, Brusoni and Orsenigo, 2010) to describe and reinforce divisions between aspects of research (e.g. basic vs. applied) and forms of organisation (e.g. public vs private sectors). These dualisms are regarded as less meaningful or even redundant in 21st century innovation (Lynskey, 2006).

We illustrate this point below, drawing upon a selection of policy instruments with significant relevance to the research base described in Germany's High-Tech Strategy 2025 (hereafter 'HTS-2025'; BMBF, 2018), Obama administration US innovation strategies, 2009-2015 (EOP, NEC and OSTP, 2009; NEC, CEA and OSTP, 2011; NEC and OSTP, 2015) and the Biden administration's US Innovation and Competition Act (hereafter 'USICA'; US Congress, 2021, sections 2102-2522). Full details of these strategies are provided in Appendix A, B and C respectively.

Our aim in analysing these strategies was to extract those policy instruments that are particularly relevant to the role of the research base in innovation in order to determine types of policy instruments employed and the policy aims they are intended to address. We coded strategies based on a framework informed by a taxonomy of science, technology and innovation policy instruments developed by the OECD (EC-OECD, 2020, p.7)[2]. Key instruments are summarised in Boxes 1 and 2 (below).

Box 1: Selected US innovation policy instruments

The recently announced **University innovation centres & institutes programme** is designed to conduct multi-disciplinary, collaborative basic and applied research relevant to key US technology focus areas to further the development, deployment, and commercialisation of innovations.

ARPA-E is a US federal agency tasked with accelerating innovation by investing in transformative energy technologies in order to create a more secure, affordable and sustainable energy future.

Public-private partnerships such as the NIH Centres for Accelerated Innovations (NCAI) and the NIH Research Evaluation and Commercialisation Hubs (REACH) are designed to accelerate translation of scientific discovery into new drugs, devices, and diagnostics that improve health for patients.

[2] Full details of the coding framework are provided in Appendix D. We employed a framework synthetic approach (Adams et al., 2016), whereby innovation strategies were analysed using this frame.

Energy Innovation Hubs are integrated, multidisciplinary research centres that combine basic and applied research with engineering, as exemplified by the Manhattan Project and AT&T's Bell Laboratories, to accelerate scientific discovery and address critical energy issues and challenges

The planned **NSF Technology Directorate** will be tasked with accelerating the translation and development of scientific advances emerging from research in key national technology focus areas into processes and products in the United States.

The **Lab-to-Market (L2M)** Initiative is designed to accelerate technology transfer for promising new innovations resulting from federally funded research. USICA included provision to expand academic technology transfer and commercialisation.

USICA included provision to support the establishment and operation of **test beds**, including fabrication facilities and cyberinfrastructure, to advance development, operation, integration, deployment, and demonstration of new, innovative technologies in key US technology focus areas.

The planned **Academic Technology Transfer programme** will support both the development and commercialisation of technologies from academic R&D, as well as building sustainable technology transfer capacity at eligible institutions

Startup America brings together an alliance of US entrepreneurs, corporations, universities, foundations, and federal agencies to accelerate the transfer of research breakthroughs from university labs and increase the prevalence and success of American entrepreneurs

Manufacturing USA is a nationwide network of public-private manufacturing innovation institutes modelled on Germany's Fraunhofer institutes that bring together companies, Federal agencies, universities, and others to develop key advanced manufacturing technologies, help businesses develop and adopt these technologies, and build a highly-skilled manufacturing workforce.

The planned **Regional Technology Hubs** are consortia of local, State, and Federal government entities, academia, the private sector, economic development organisations, and labour organisations undertaking regional innovation strategies to support emerging technology development, innovation diffusion, regional economic development and address societal challenges.

The **Hands-on Learning** programme is designed to expand the STEM workforce pipeline by inspiring students to pursue careers in US STEM fields and broaden participation in the STEM workforce by underrepresented population groups.

The **National engineering biology R&D initiative** aims to advance areas of research at the intersection of the biological, physical, chemical, data, and computational sciences and engineering to accelerate scientific understanding and technological innovation in engineering biology

The **Small Business Innovation Research (SBIR**) and **Small Business Technology Transfer (STTR)** programmes are highly competitive public procurement programmes that encourage domestic small businesses to engage in Federal R&D with the potential for commercialisation and to address specific federal innovation needs, either individually (SBIR) or in collaboration with public research institutes (STTR).

Box 2: Selected German innovation policy instruments

Research Campus is a German public-private partnership to support commercial development of new, highly complex fields of research with a high research risk and particular potential for breakthrough innovations, through large-scale, long-term approaches towards single-site cooperation between science and industry.

SPRIN-D is the recently established German federal agency modelled on DARPA, supporting breakthrough innovation through financing, assembling teams and facilitating networking.

Transfer initiative Germany's HTS-2025 has also announced the development of a new transfer initiative to remove bottlenecks on the path from idea to market and help companies translate scientific research results into products and processes.

The **Industrial Collective Research (IGF)** initiative focuses on pre-competitive technology transfer and diffusion among collectives consisting of private sector firms and research institutions.

The German **r+Impuls** initiative supports further development of innovations to an industrial scale through testing technical and economic feasibility in prototype and reference installations.

The **EXIST Start-up Culture** programme is designed to promote an entrepreneurial culture at German universities, with specific projects in the local, regional or international environment.

The **Clusters4Future** programme is a competitive process designed to develop powerful regional clusters in emerging fields of technology and innovation with high growth potential. They are designed to bring the most promising research findings to application sooner and faster than previous cluster approaches.

The **Go-Cluster** programme supports cluster management organisations with the development of their innovation cluster.

The **WIR! - Change through Innovation in the Region** programme supports new broad-based regional alliances which jointly identify fields of innovation, to encourage sustainable innovation-based structural change in all structurally weak regions in Germany.

SME 4.0 competence centres is a German nationwide network of centres providing free services to entrepreneurs and employees in the demonstration and testing of new technologies.

Our analysis shows that forms of organisation which enable collaborative and co-creative R&D partnerships and open innovation are being promoted in order to reduce the division of labour between 'public' (universities and public laboratories) and 'private' (commercial firms), associated with the linear model of innovation. Examples include:

- Instruments to promote collaboration and co-creation for R&D and innovation (e.g. Manufacturing USA, US university innovation centres & institutes, and US public-private partnerships; Germany's research campus, Clusters4Future programme and the federal agency for breakthrough innovation, SPRIN-D)
- Instruments to encourage mobility of human resources between the public and private sectors [e.g. as part of the US National engineering biology R&D initiative; Germany's Industrial Collective Research (IGF) programme].

Additionally, public investment is being provided to help organisations overcome challenges across the entire innovation chain, from basic research through applied research, product development, deployment and diffusion to support translation of scientific advances into innovative applications and help companies de-risk investments (Laplane and Mazzucato, 2020). This signals an erosion of the basic-applied dualism, i.e. the linear model's representation of the innovation process as sequential, which has historically justified the prioritisation of basic research over applied research in order to prime the innovation process (Kline and Rosenberg, 1986). Examples include:

- Instruments to support academic technology transfer (US Lab-to-Market programme, the planned academic technology transfer programme and NSF's planned Technology Directorate, and the planned German transfer initiative)
- Instruments to support multidisciplinary centres or programmes that provide both direction to research efforts and the necessary support to develop and demonstrate technologies emerging from this research (German SPRIN-D and research campus; US ARPA-E)
- Instruments to promote high-risk/high reward or breakthrough research with subsequent translation to application (German research campus and SPRIN-D; US Energy Innovation Hubs and ARPA-E)
- Instruments to support broader diffusion of innovations across national and regional levels (US Regional Technology Hubs; Germany's Industrial Collective Research (IGF) programme).

The linear model has also been used to justify support for organisations in which basic and applied research is performed, namely universities and public research institutes (Flink and Kaldewey, 2018). However, the erosion of the basic-applied dualism has been accompanied by a policy emphasis on a broader role for these organisations, both in terms of engagement in non-R&D activities downstream in the innovation process (i.e. product development, deployment and diffusion) and in strengthening wider innovation systems. Examples include:

- Instruments to develop and ensure open access to R&D infrastructure (US test beds, German r+impuls programme)
- Instruments to encourage institutional change and the emergence of an entrepreneurial culture within academia (Germany's EXIST Start-up Culture initiative; USICA's planned academic technology transfer programme)
- Instruments to support the emergence and growth of innovation networks and clusters [Germany's Change through Innovation in the Region (WIR!), Go-Cluster and Clusters4Future programmes; US Regional Technology Hubs and Manufacturing USA]
- Instruments to finance R&D and innovation, including *equity finance* (Germany's SME-innovative programme, US Startup America), *leveraging private investment* (Germany's Clusters4Future, US university innovation centres & institutes) and *financial support for business R&D and innovation* (Germany's ZIM cooperation projects; US Small Business Innovation Research (SBIR) / Small Business Technology Transfer (STTR) programmes)
- Instruments to develop workforce skills (Germany's SME 4.0 competence centres; US Hands-on learning programme)
- Instruments to facilitate formal consultation with experts or stakeholders (Germany's Platform for Artificial Intelligence; US National Engineering Biology R&D initiative)
- Instruments to build demand for innovation through public procurement (US SBIR and STTR programmes, HTS-2025's aim of more effectively leveraging innovation-oriented public procurement).

The second overarching trend from the innovation strategies analysis is the incorporation of elements of the transformative change framework outlined earlier, as governments experiment with mission-oriented innovation policies (Mazzucato, 2018). In particular, consideration of innovation directionality is increasingly incorporated into the design of many policy instruments outlined in HTS-2025, Obama innovation strategies and USICA, so that ambitions for seizing opportunities offered by emerging technologies, tackling societal challenges, or delivering inclusive and sustainable growth may be realised.

As noted elsewhere (OECD, 2021, p.191), Germany and the US employ different approaches to incorporating directionality into innovation policy. HTS-2025 has been devised as a national mission-oriented strategic framework to help coordinate actions among a wide range of actors focussed on six key missions (Health & care: Sustainability, climate protection and energy; mobility; Urban and rural areas; Safety and security; and Economy and work 4.0). By contrast, the Obama-administration strategies use a challenge-based approach implemented by dedicated lead agencies or programmes, focused on three overarching goals (catalysing breakthroughs for national priorities; promoting competitive markets that spur productive entrepreneurship; investing in the building blocks of American innovation). USICA retains this challenge-based approach and emphasises key emerging technologies (such as AI, machine learning and autonomy; high-performance computing and semiconductors; quantum technology; robotics, automation and advanced manufacturing; biotechnology, medical technology, synthetic biology and genomics; advanced communications/immersive technology; cybersecurity; advanced energy and industrial efficiency technologies and advanced materials science), as well as tackling environmental change and broadening geographic and demographic participation in innovation.

Effects of the pandemic on innovation systems

2 Effects of the pandemic on innovation systems

Question addressed in this section

- How has the pandemic affected innovation and key actors in innovation systems?

Summary of key findings:

- Pandemic is challenging the largely reactive approach to innovation policy
- Effects of the pandemic on innovation and key actors include:
  - **Public and charitable sector R&D investment**
    - Rapid global expansion of pandemic-related funding
    - Higher levels of public R&D funding continuing into the economic recovery
  - **Private sector R&D and investment**
    - Decreased productivity within UK firms
    - Significant disruption to industry innovation strategies and decreased R&D investment across most sectors, which is expected to be prolonged
    - Increased private sector R&D investment by some firms, leading to a concentration of innovative activities among a small group of firms
    - Mixture of creative destruction (lower productivity firms being replaced by higher productivity firms in some sectors) and destruction (lower productivity firms being lost and not being replaced by higher productivity firms in others)
    - Disruption of global supply chains
  - **Research and innovation rate**
    - Rapid adoption of policy measures to mobilise innovation systems
    - Responsiveness and agility to enable rapid responses to COVID-related need
    - Increased rate of innovation
    - Increased openness of science and innovation
    - Expansion and disruption of international collaborations
  - **Levels and focus of university-industry innovation partnerships**
    - Significant disruption to university-industry partnership activities and ability of universities to contribute to innovation
  - **Research and innovation directionality**
    - High elasticity of science (researchers switching focus to COVID-related issues)
    - Insufficient anticipation of consequences of R&D and reflexivity concerning moral responsibilities to society within the innovation system
    - Bias against funding high risk-high reward research
    - Gravitation towards easier, lower-value and less promising inventions
  - **Societal challenges**
    - New policy priorities to ‘build back better’

Innovation strategies prior to the pandemic were largely reactive in nature. The scale and longevity of COVID's public health and socio-economic effects around the world is challenging the adequacy of such approaches, with growing calls for more proactive approaches to be developed (OECD, 2021, p.190). This section explores emerging evidence on some of the main effects of the pandemic on the research and innovation system, highlighting particular inadequacies of reactive approaches to innovation policy.

2.1 Impacts on public and charitable sector R&D investments

The pandemic saw a rapid expansion in funding for COVID R&D projects, with global public, private and third sector funding commitments totalling USD9.1bn by September 2020 (Paunov and Planes-Satorra, 2021a, p.12).

Higher levels of public R&D funding look set to continue into the economic recovery as a consequence of innovation-led growth policies. The US government is currently proposing to authorise $110bn for R&D, the EU has increased Horizon Europe funding by €13.5bn, China intends to increase R&D spending by more than 7% and the UK is set to double R&D public spending over the next five years (EC, 2020; HM Government, 2020; Mallapaty, 2021; US Congress, 2021).

However, charitable funding has been hit hard by the pandemic and this is likely to lead to reduced R&D funding by medical research charities in the UK (Thomas and Nanda, 2021).

2.2 Impacts on private sector R&D and innovation

Decreased productivity

The pandemic is likely to have resulted in a significant drop in productivity within UK firms, although this has been masked within a surprisingly limited decrease in overall productivity measures (-5% in 2020Q4) (Bloom et al., 2020). This masking is believed to be due to staff furloughing, and processes where lower productivity firms are replaced by higher productivity firms in some sectors [known as *creative destruction* (Schumpeter, 1942)] or not replaced at all in other sectors (known as *destruction*). This is important because productivity growth is a determinant of higher standards of living. This, as well as the historic lag in UK productivity behind that of many major developed economies before the pandemic (OECD, 2018), has seen an increased focus on productivity in the UK's Innovation Strategy (BEIS, 2021).

Disrupted business innovation strategies and R&D investments

The pandemic has also disincentivised business R&D and innovation, resulting from, for example, weakened firm financial resources, market volatility, weak market demand, and precautionary behaviour caused by uncertainty (Roper and Turner, 2020; Stiglitz, 2021; Stiglitz and Guzman, 2021).

These disincentives have disrupted firms' innovation strategies and R&D investments. Surveys have reported rates of total or partial cancellation of R&D activities of 44% for a sample of Italian firms (Brancati, 2020), and 44% (internal R&D activities) (NCUB and UCI, 2021) and 26% (Roper and Vorley, 2020) for samples of UK firms. Other disruptions, such as postponement and reductions in scope have also been noted. In terms of R&D investments, 51% of surveyed UK firms reported a decrease of at least 10% in the early months of the pandemic (Roper and Vorley, 2020). This trend of reduced business expenditure on R&D (BERD) in times of crisis is known as *procyclicality*, and was also noted following the 2008 financial crash (Aghion et al., 2012; Roper and Turner, 2020).

At the same time, the pandemic has opened up new opportunities and incentivised innovation in some firms and sectors through the promise of high returns on investment or heightened urgency of public health needs (Gross and Sampat, 2021), or simply through relaxing previously constrained strategic decision-making (Wenzel, Stanske and Lieberman, 2020). This is known as *counter-cyclicality* (where business R&D rises during a crisis). Surveys of UK firms saw 10% reporting increases in R&D investment (Roper and Vorley, 2020) and 44% planning for increased internal R&D activities in the short term (NCUB and UCI, 2021).

Pro- and counter-cyclicality have important implications for firms' resilience, survival and competitiveness. Evidence from the 2008 financial crash suggests that, where firms were able to continue investing in R&D-based innovation during a recession, they were more likely to survive the crisis and emerge more competitive (Antonioli et al., 2013; Soininen et al., 2012) with enhanced financial performance (Castillejo, Barrachina and Sanchis-llopis, 2019; Flammer and Ioannou, 2021; Spescha and Woerter, 2019). R&D investment was an effective survival strategy for innovative firms capable of producing intellectual properties during recessionary periods (Jung, Hwang and Kim, 2018).

That some firms are able to continue investing in R&D while others are not has important implications for the economy. The 2008 crash concentrated innovative activities among a small group of firms, namely innovative firms already established in markets (incumbents) and, immediately after the crisis, innovative small enterprises and new market entrants (Archibugi, Filippetti and Frenz, 2013a, 2013b). While significantly disruptive to the economy, it can have some beneficial *creative destruction* effects with lower productivity firms being replaced by higher productivity firms, helping to make the economic system more innovative overall (Schumpeter, 1942). However, the COVID-induced economic crisis appears to be different in that it has resulted in both creative destruction and *destruction* (lower productivity firms being lost and not replaced by higher productivity firms in some sectors) (Bloom et al., 2020, p.17).

Procyclical innovation will also have a persistent impact on the economy even after COVID-19 has been controlled, known as a *hysteresis effect*. Evidence from previous pandemics suggests reduced innovation outputs may persist for approximately seven years after a pandemic has been controlled (Wang, Zhang and Verousis, 2021).

Disruptions to global supply chains

The pandemic has also disrupted the resilience of complex, nested, and interconnected systems to deliver goods and services, hampering the supply of pandemic countermeasures to many countries (Hynes et al., 2020). This highlighted infrastructure and capability gaps in UK life science manufacturing as a consequence of declining capacity over the last 25 years (HM Government, 2021). Rebuilding this capacity is a goal of the UK's Innovation Strategy (BEIS, 2021).

2.3 Research and innovation rate

High responsiveness and agility

Perhaps the most significant beneficial effect of the pandemic, in terms of innovation, was the rapid adoption of policy measures to mobilise innovation systems, the subsequent *responsiveness* of the system (responding to new knowledge and to emerging perspectives, views and norms), and its *agility* (adopting processes to enable rapid responses to COVID-related need). That development, manufacture and distribution of the first vaccines was achieved in less than one year is unprecedented (Ball, 2021), and governments are attempting to learn from this success to increase innovation rate more broadly (BEIS, 2021, p.19).

The increase in innovation based on collaboration and knowledge flows between different organisations was instrumental to this responsiveness and agility (Patrucco et al., 2021). In particular, the role of public-private partnerships, such as the Oxford-AstraZeneca vaccine development in the UK and Operation Warp Speed in the US which successfully accelerated development, manufacture and distribution of COVID-19 vaccines, therapeutics and diagnostics, has been widely discussed. Collaborative and open innovation approaches are also being advocated as a route towards faster economic recovery (Chesbrough, 2020). Both public-private partnerships and minimising boundaries between discovery, invention, and development are being emphasised in the UK's innovation strategy (BEIS, 2021, p.19).

Increased openness of science and innovation

The proliferation of *open science*[3] initiatives and increased interdisciplinarity were also critical to boosting the responsiveness and agility of innovation systems (Paunov and Planes-Satorra, 2021b). However, a number of challenges remain to be addressed, not least the findability, accessibility, interoperability and reusability of data; international data standards; open access to publications; quality control issues associated with pre-prints; and coordination issues between collaborative research platforms (OECD, 2020a).

Expansion and disruption of international collaborations

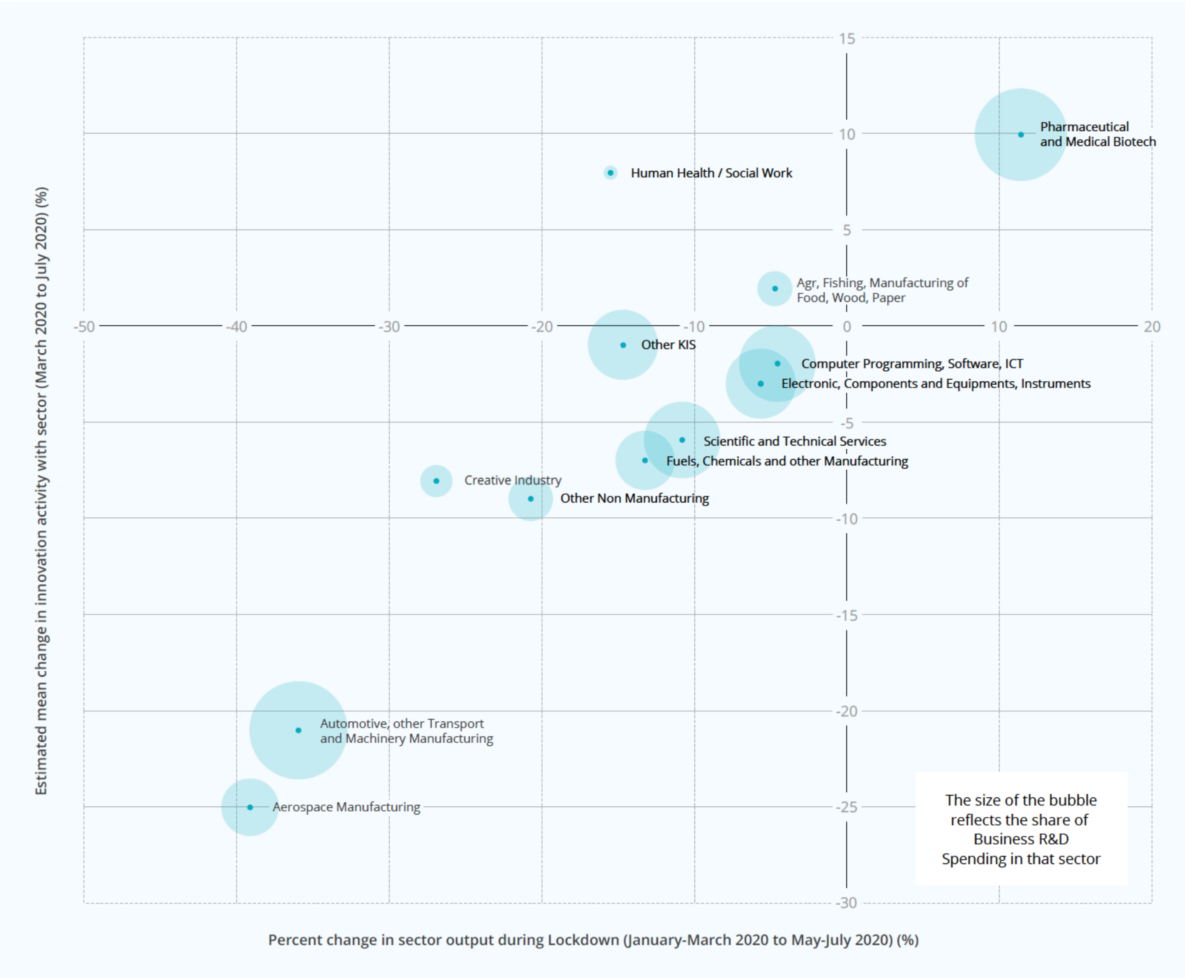
International collaborations were also important to the COVID response, even though these were severely disrupted by the curtailed movement of people. This was partially mitigated through increased use of digital technologies, and new or expanded international governance models and coordinating mechanisms (Collins and Stoffels, 2020). The effects of the pandemic on international research collaborations are not well understood, and are the subject of current research (NSF, 2020). The UK's innovation strategy (BEIS, 2021, p.19) has emphasised increasing international collaborations as part of the 'UK as a science superpower' agenda.

[3] Unhindered access to scientific articles and publicly funded research data, and collaborative research enabled by ICT tools and incentives (Paunov and Planes-Satorra, 2021b, p.25)

2.4 Changing levels and focus of university-industry innovation partnership activities

The past few decades have seen universities become much more important and strategic partners for innovation for many (particularly large) companies. The disruptions to business innovation strategies, however, have impacted levels of innovation-focused partnerships and activities with universities, with those sectors most adversely affected by the pandemic seeing greatest disruptions (Figure 1).

Figure 1| Relationship between change in the sector output during first lockdown (March to July 2020) and the change in level of innovation activity between universities and partners in the sector



Notes: (i) change in sector output for other knowledge intensive services (Other_KIS) excludes financial and insurance services; (ii) mean change estimated by taking the following points in each category: Collapsed (-51%); Significantly decreased (-35%); Moderately decreased (-13%); About the same (0%); Moderately increased (13%); Significantly increased (21%). Source: (Ulrichsen, 2021)

Many R&D-active UK businesses reported delaying, reducing, refocusing or cancelling some R&D projects with universities during the early phase of the pandemic (NCUB and UCI, 2021). However, there is evidence showing that, at least in the early phase, some UK businesses found ways of maintaining or even increasing activity with universities (Roper and Vorley, 2020). From the perspective of UK universities, 45% reported decreases in partnership activities while 23% saw activities increase between March-July 2020 (Ulrichsen, 2021), particularly in pharmaceuticals, medical biotechnology, and health and social work. UK universities reported the greatest decreases in the level of innovation activities and partnerships with SMEs (Ulrichsen, 2021). We found a decrease in overall levels of innovation-focused partnership activities across UK universities of 13% between March 2020 and July 2021 (Ulrichsen and Kelleher, 2022).

2.5 Research and innovation directionality

Highly responsive and adaptable research base

The pandemic has highlighted a number of noteworthy issues associated with the direction of research and innovation. First is the phenomenal degree to which scientists are willing to change the direction of their work to tackle COVID-related issues (known as 'elasticity of science', Myers, 2020). It has been reported that public research institutions (including universities) were a main driver of COVID vaccine innovation, being 10% more likely than private firms to conduct clinical trials, leading to an increase (38%) in clinical trials with minimal crowding-out of non-COVID trials, and an R&D pandemic response 7-20 times greater than would have been implied by market size (Agarwal and Gaule, 2021). These are encouraging findings in demonstrating the critical role of universities in rapidly scaling responses to societal challenges.

Pandemic reveals insufficient anticipation

Second, that the pandemic was a known but underestimated risk (Tooze, 2021) illustrates insufficient *anticipation* of consequences of R&D and *reflexivity* concerning moral responsibilities to society within the innovation system. Pre-pandemic investment in COVID countermeasures by both the private sector (due to lack of demand and market failure-associated issues) and public sector (due to prioritisation of domestic over global health needs and capability gaps) was insufficient to avoid global disruption (Abi Younes et al., 2021; Mazzucato and Kattel, 2020). Crises often present what is known as an *asymmetric loss function* (Gross and Sampat, 2021), where overinvesting in R&D pre-pandemic proves less costly than underinvesting. In the UK, government spending on the COVID response was greater than that on all innovation in at least the last thirty years combined (BEIS, 2021, p.19), prompting the government to seek to prioritise innovation in order to meet future opportunities and threats.

Bias against funding high risk-high reward research

Third, a pre-pandemic bias against funding risky research and breakthrough technologies has been highlighted. Breakthrough technologies, such as mRNA used in the development of Pfizer-BioNTech and Moderna vaccines, have been instrumental in addressing the public health crisis but struggled to win funding within a risk-adverse public funding system (Franzoni, Stephan and Veugelers, 2021). The UK's innovation strategy (BEIS, 2021, p.19) has emphasised the need for a greater acceptance of risk in public sector innovation investments.

Gravitation towards lower-value and less promising inventions

Fourth, the high investment returns and increased urgency associated with the public health crisis induced firms to race towards easier, lower-value and less promising inventions, such as repurposed drugs (Bryan, Lemus and Marshall, 2020) and crude ventilators unsuited to patient needs (Sanchez-Graells, 2021). A similar trend was observed during the 2008 financial crash where firms rationalised R&D expenses and adopted low cost innovation strategies (Laperche, Lefebvre and Langlet, 2011).

2.6 Grasping opportunities to address societal challenges

The pandemic has exacerbated pre-existing social and regional inequalities and disproportionally affected vulnerable segments of society (Crisp and Waite, 2020). It has also been linked to climate change as being characteristic of the Anthropocene, the era in which science and technology has been used to build a life-style based on abundance but with intensifying ecological consequences (Asayama et al., 2021; Heyd, 2021; Schot, 2020).

Consequently, there is a strong view that the pandemic offers policymakers an opportunity to 'build back better', i.e. to reset economies to address societal challenges, seize opportunities and deliver inclusive and sustainable growth (Martin, 2021; OECD, 2020b). This is increasingly influencing prioritisation within the innovation strategies of countries including the US and UK, and the EU (EU Council, 2020; HM Treasury, 2021; White House, 2020).

Innovation policy during the pandemic

3 Innovation policy during the pandemic

Question addressed in this section

- How does innovation policy during the pandemic differ from pre-pandemic innovation policy?
- Why should public funding be invested through the crisis period of the pandemic to help universities sustain their innovation-focused activities with innovation partners?

Summary of key findings:

Innovating during crises differs from that in normal times in terms of:

- Large social returns on R&D investment
- Need to act quickly
- Objective shifts from non-specific, broad technological advance to crisis resolution.

Innovation policy during the pandemic emphasised interventions not justified by a market fixing approach, including:

- Prioritising applied research to address urgent problems
- Focusing on short-term results
- Coordinating research efforts and knowledge flows within innovation systems
- Funding overlapping and parallel R&D efforts
- Focusing on development, demonstration and diffusion of innovations.

Public funding during the crisis enabled universities to:

- Prioritise applied research in response to urgent needs
- Focus on short-term results
- Focusing on development, demonstration and knowledge diffusion from lab-to-application
- Coordinate research efforts and knowledge flows.

3.1 Innovation policy during the pandemic

Accelerating Innovation is often at the heart of resolving many crises of the scale, threat and disruption as COVID. While predominantly reactive, pre-pandemic innovation policies proved inadequate in avoiding and subsequently containing COVID-19 before reaching pandemic phase, the rapid adoption of emergency policy measures was instrumental in mobilising innovation systems to respond to the crisis with unprecedented agility. Many of these measures were predicated on governments taking an active role in designing and enforcing policies which would not be justified within a market fixing approach. Consequently, there is significant interest in learning lessons from the success of emergency innovation policy.

There is emerging evidence that innovating during extreme crises differs from innovation in normal times in two important respects: the large social returns on R&D investment and the need to act quickly (Gross and Sampat, 2021). Further, these authors argue the objective of innovation changes, from non-specific and broad technological advance to crisis resolution (i.e. it provides a very specific objective to those involved).

Given this, innovation policies need to adapt during crisis periods. Learning lessons from history, Gross and Sampat argue that for crisis periods, innovation policies need to take on additional roles to address crisis-specific pressures and challenges at pace and scale. They suggest five key areas of action:

- *Prioritising applied research to address urgent problems* recognising that solving immediate crisis-induced challenges requires making best use of the knowledge available and translating it into practical applications at speed
- *Focusing on short-term results*, which may favour funding R&D organisations with sufficient facilities and personnel that can deliver the best results in the shortest possible time over other cost and distributional concerns
- *Coordinating research efforts* as well as knowledge flows within innovation systems beyond simply providing funding
- *Funding overlapping and parallel R&D efforts* to ensure redundancy where solution uncertainty was high – i.e. creating multiple options recognising that many will fail
- *Focusing on development, demonstration and diffusion of innovations*, rather than invention alone, to ensure that discoveries make their way quickly from lab-to-application. This could require effective and deliberate coordination of research, innovation and production activities, and more actively working to strengthen the links between activities and organisations to ensure rapid and effective feedback and continual refinement of technologies to ensure they met practical needs. This includes greater focus on technology demonstration, testing and adoption, including increasing production capacity at risk and minimising barriers to appropriability (for example through more liberal conditions regarding IP ownership).

Turning to the COVID crisis, Table 4 captures examples of different types of policy instruments and other measures that have been introduced or significantly amplified to help resolve the crisis.

Table 4| US and German innovation strategies: themes and example instruments

Policy aim	Instrument	Reference
Prioritisation of applied research	Accelerated or repurposed funding initiatives for applied research and to mobilise industry	(Paunov and Planes-Satorra, 2021a, p.13)
Coordination	National and international coordination and information-sharing mechanisms (e.g. collaborative networks, multilateral and cross-ministerial strategies, scientific advice-giving bodies)	(Paunov and Planes-Satorra, 2021a, p.11)
	Open competitions and hackathons to gather inputs from all parts of STI systems	(Paunov and Planes-Satorra, 2021a, p.14)
	Initiatives to facilitate access to research infrastructures including databases and tools	(Paunov and Planes-Satorra, 2021a, p.16)
Target high-risk R&D projects to high-value areas	Targeted R&D subsidies to incentivise development of difficult but high-value innovations with potential as pandemic countermeasures	(Bryan, Lemus and Marshall, 2020)
Overlapping and parallel R&D efforts	Portfolio management and increased risk acceptance in public investments in innovation	(Mazzucato and Semieniuk, 2017)
Development, demonstration & diffusion	Public-private partnerships to support not just R&D, but also manufacture and distribution of COVID countermeasures	(Abi Younes et al., 2021)
	Advanced market commitments (where governments guarantee payments for future innovations meeting technical benchmarks)	(Abi Younes et al., 2021)
	Relaxation of competition law restrictions which might hinder industry partnerships	(Bryan, Lemus and Marshall, 2020)
	Regulatory flexibilities to ensure rapid responses while maintaining safeguards	(Paunov and Planes-Satorra, 2021a, p.16)
	Intellectual property measures to accelerate the examination of COVID-19-related patent applications submitted by SMEs without incurring additional fees	(Paunov and Planes-Satorra, 2021a, p.17)
	Measures to tackle the spread of public health misinformation	(Paunov and Planes-Satorra, 2021a, p.18)

3.2 Universities and innovation in a crisis

Emerging evidence also suggests that universities responded broadly in line with types of innovation policy goals outlined by Gross and Sampat, as discussed below. These stand as justifications for public funding for universities during a crisis.

- **Prioritising applied research to address urgent problems**: Universities shuttered many non-COVID research projects (Barrero, Bloom and Davis, 2020) while pivoting to COVID-related projects, in particular boosting the volume of clinical trials (Agarwal and Gaule, 2021).
- **Focusing on getting short-term results**: Universities accelerated their R&D activities to the extent that the time between identifying a new innovation need and innovation launch (i.e. market introduction or public communication of an innovation) was about the same for innovations undertaken by universities as for incumbent firms (Ebersberger and Kuckertz, 2021).
- **Coordinating research efforts and knowledge flows**: Universities sought to coordinate research and innovation efforts, for example by launching competitions for open-source ventilator design (Chesbrough, 2020) and through participation in national and international coordination initiatives (Paunov and Planes-Satorra, 2021a).
- **Focusing on the development, demonstration and diffusion of innovations**: Universities participated in public-private partnerships and consortia (Tietze et al., 2020) to facilitate translation of research into applications. They also adopted patent and licencing strategies to minimise appropriability barriers for COVID-related technologies (Contreras, 2021) and other new ways of working with external partners to increase agility, responsiveness, flexibility and accessibility (Ulrichsen, 2021). In addition, universities engaged in non-traditional downstream innovation activities, such as using 3D printing facilities to produce personal protective equipment (Johnstone and McLeish, 2020).

Innovation during the recovery

4 Innovation during the recovery

Question addressed in this section

- How should innovation policy adapt to drive an innovation-led economic recovery as we move beyond the pandemic?
- Why should public funding be invested in universities during the recovery phase?

Summary of key findings:

- Post-pandemic innovation policy is increasingly shifting away from reactive, predominantly market-driven approaches to a more proactive 'systems transformation' approach, combining a focus on overcoming system failures with system transformative elements, including:
  - Enhanced anticipation of innovation's opportunities, challenges, spillover effects and consequences
  - Improved directionality through taking account of a broad range of views concerning possible development paths
  - Broadened inclusion in terms of both participation in innovation processes and a more equitable distribution of innovation benefits
  - Increased deliberation involving iterative exchanges of views, requiring enhancing societal capacities to understand, communicate on, and shape technological development
  - Responsible innovation through encouraging ethical, anticipatory and reflexive approaches from the private sector, particularly for emerging technologies.
- Evidence suggests that UK universities are adapting through the pandemic and are well-placed to meet the demands and opportunities of a more proactive innovation policy approach.
- Post-pandemic public 'recovery' funding should focus on enabling universities to:
  - Address ongoing and emerging COVID-related public health needs
  - Strategically adapt and pivot innovation-focused activities to meet the changed needs of economies and societies post-pandemic
  - Maintain their R&D and innovation capabilities and infrastructure through the crisis until demand for R&D, KE, and innovation activities recovers or new opportunities are unlocked, thereby enabling long-term growth.

4.1 Innovation policy during the recovery

Socio-economic, political and industrial landscapes are being significantly disrupted as we move through the pandemic, with the world likely to look very different post-pandemic compared with that of 2019. Looking at the economy, while some sectors are experiencing creative destruction (higher productivity firms replacing lower productivity firms leading to higher overall productivity in the sector), others are experiencing prolonged downturn of R&D and innovation spending through the depths of the economic crisis. Some sectors are experiencing destruction where lower productivity firms are not being replaced by higher productivity firms leading to low overall sectoral productivity. The ongoing effects of the pandemic are such that pure market forces alone may be inadequate to restore economic growth (Stiglitz, 2021).

There are increasing calls that plans for the economic recovery should not emphasise getting back to 'business as usual', but rather that the recovery should build a more sustainable, equitable and resilient economy (Martin, 2021; OECD, 2020b; Schwab and Malleret, 2020; Stern et al., 2020). To this end, the OECD (2021, pp.194–198) has speculated that the pandemic may accelerate the shift away from predominantly market-driven innovation policy to a more proactive 'systems transformation' approach promoting a managed transition to more sustainable, equitable and resilient futures. Such an approach combines a focus on the types of system failures typical of pre-crisis innovation policies (see Section 2) with the following more proactive elements:

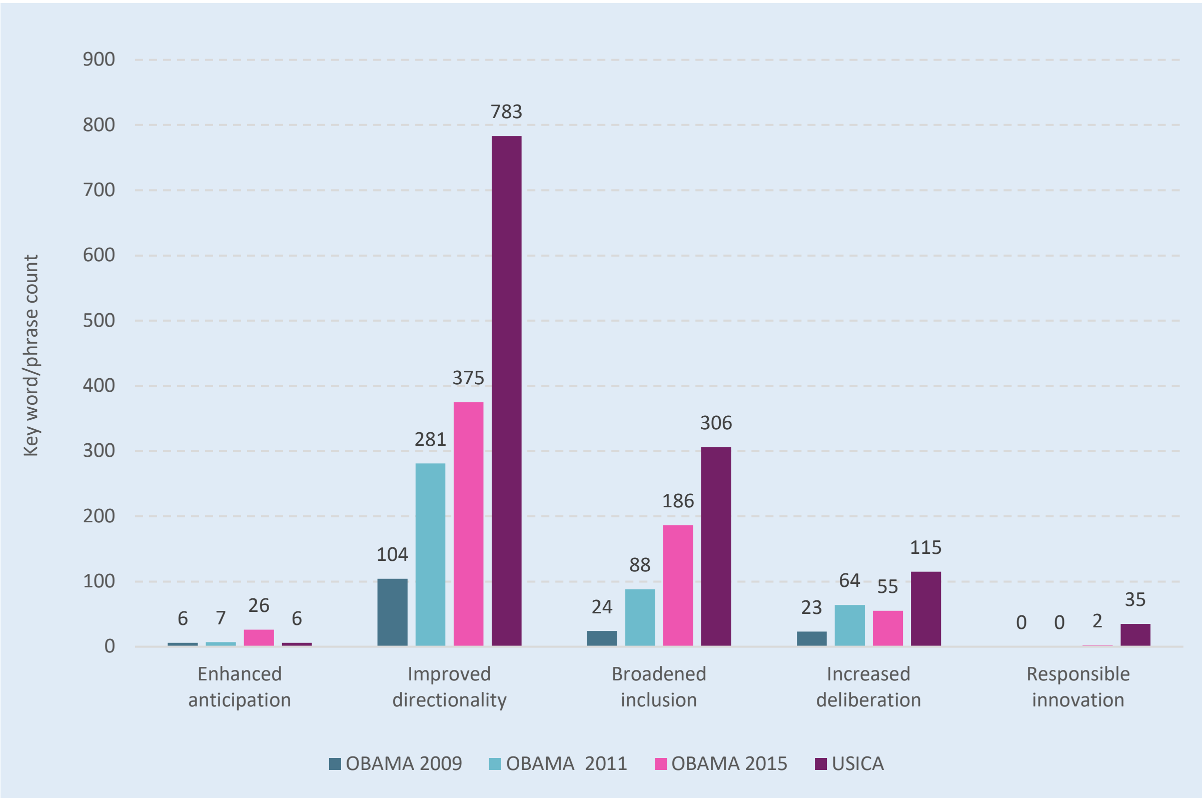
- *Enhanced anticipation* of innovation's opportunities, challenges, spillover effects and consequences through generating multiple development paths, identifying the most desirable paths through societal experimentation and examining possible consequences of these paths (Schot and Steinmueller, 2018)
- *Improved directionality* through taking into account a broad range of views concerning a range of possible development paths, challenging incumbents' views, and finally narrowing in on a limited number of acceptable paths and their connections to societal goals (Schot and Steinmueller, 2018)
- *Broadened inclusion* in terms of both participation in innovation processes (e.g. by industry, the social sciences and humanities, international researchers, civil society and the public) and ensuring a more equitable distribution of innovation benefits (Chataway, Hanlin and Kaplinsky, 2014)
- *Increased deliberation*, involving an iterative exchange of views, which in turn requires enhancing the capacities of societies to understand, communicate on, and shape technology through the course of development so that the technology advances under conditions of trust
- *Responsible innovation* through encouraging an ethical, anticipatory and reflexive approach from the private sector, particularly for emerging technologies.

In order to explore what elements of a 'systems transformation' approach are being adopted in innovation strategies, we compared the three US pre-pandemic innovation strategy developed under President Obama (EOP, NEC and OSTP, 2009; NEC, CEA and OSTP, 2011; NEC and OSTP, 2015) and the emerging US innovation strategy aimed at driving an innovation-led economic recovery [US

Innovation and Competition Act ('USICA', US Congress, 2021, sections 2102-2522)][4]. This analysis involved counting the use of relevant keywords or phrases within a specific strategy document (see Appendix E), which gives an indication of how strongly emerging strategic aims are emphasised.

The results of this analysis (Figure 2) show that the emphasis on improved directionality and broadened inclusion has increased in successive innovation strategies, and in particular within USICA relative to pre-pandemic strategies. Increased deliberation is emphasised to a lesser extent across all strategies, but also sees a significant increase in USICA. Responsible innovation is rarely emphasised in pre-pandemic strategies, but has become more significant within USICA. By contrast, enhanced anticipation is less emphasised within USICA than the final Obama administration strategy. This suggests that US innovation strategies are largely shifting towards more proactive 'systems transformation' approaches, although without significant emphasis on anticipation.

Figure 2| Content analysis of US pre-pandemic and recovery innovation strategies



[4] To do this we carried out a comparative content analysis (Short et al., 2010), using codes informed by Stilgoe et al's (2013) framework for responsible innovation.

4.2 Public policy, universities, and innovation for the recovery

Following consideration of the emerging evidence of COVID-19's impacts on innovation and key actors in the innovation system, as well as evidence from previous crises, three justifications for public funding for universities in the post-pandemic period may be made.

Addressing ongoing public health needs

First, the pandemic is ongoing and will continue to have public health effects for some time to come. Public funding is justified to enable universities to continue their successful and critical role of dealing with these effects, specifically through prioritising applied research to respond to urgent pandemic-related needs, focusing on short-term results, the development, demonstration and diffusion of technologies, and coordinating research efforts and knowledge flows.

Strategic adaptation of universities to pursue emerging opportunities

Second, the post-pandemic socio-economic, political and industrial landscapes have been disrupted by the pandemic, and this disruption will likely continue even after the pandemic has been controlled. Given the relatively rapid and significant changes to innovation priorities and conditions across economies, universities are likely to have to adapt and reconfigure to enable them to continue to play an active role in driving innovation during the recovery period. Public funding is justified to enable this process of adaptation and reconfiguration within universities.

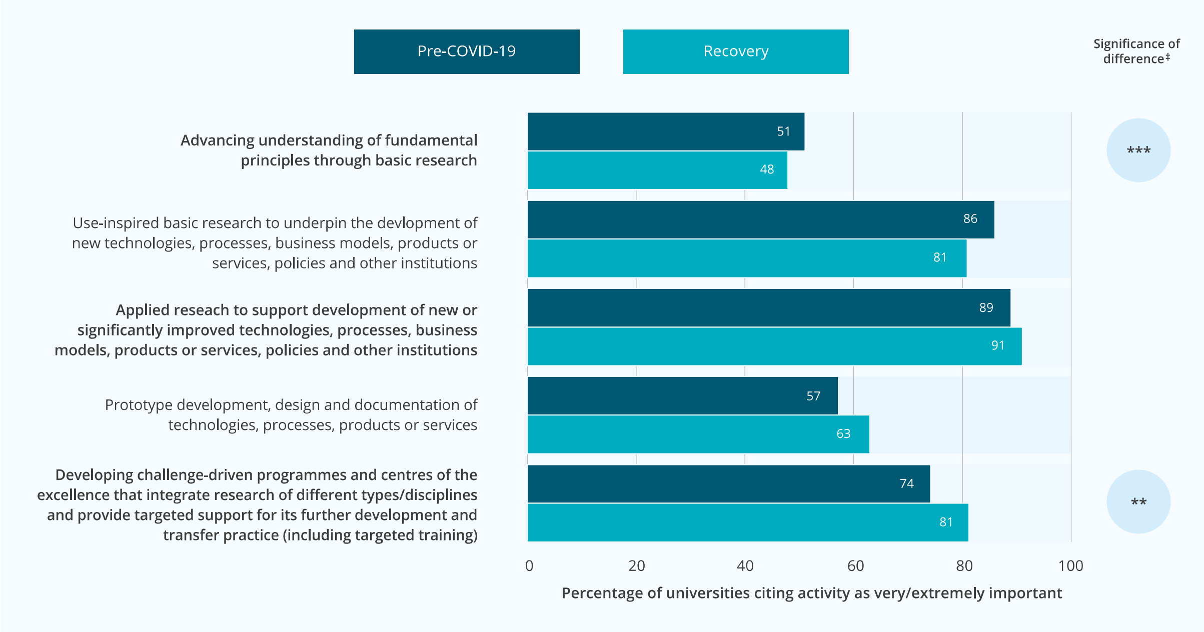
Maintaining capabilities and infrastructure for long-term growth

Third, just as the pandemic disrupted business R&D strategies, it has also disrupted university innovation strategies. In a prolonged period of depressed demand for R&D collaborations, partnerships, and wider knowledge exchange services, there is a danger that university capabilities, infrastructure and core partnerships may be lost in the short term and will be hard to regain when innovation resumes in these sectors. It is likely that universities that are unable to maintain these capabilities and infrastructure through the crisis will emerge from the pandemic weaker and less capable of contributing to economic recovery, much like the pro-cyclical businesses discussed in Section 3. Consequently, public funding is justified to enable universities to maintain capabilities and infrastructure through a prolonged recessionary period of depressed demand for R&D, KE, and innovation activities in order to foster long-term growth (OECD, 2009, p.28).

4.3 Emerging university strategic priorities

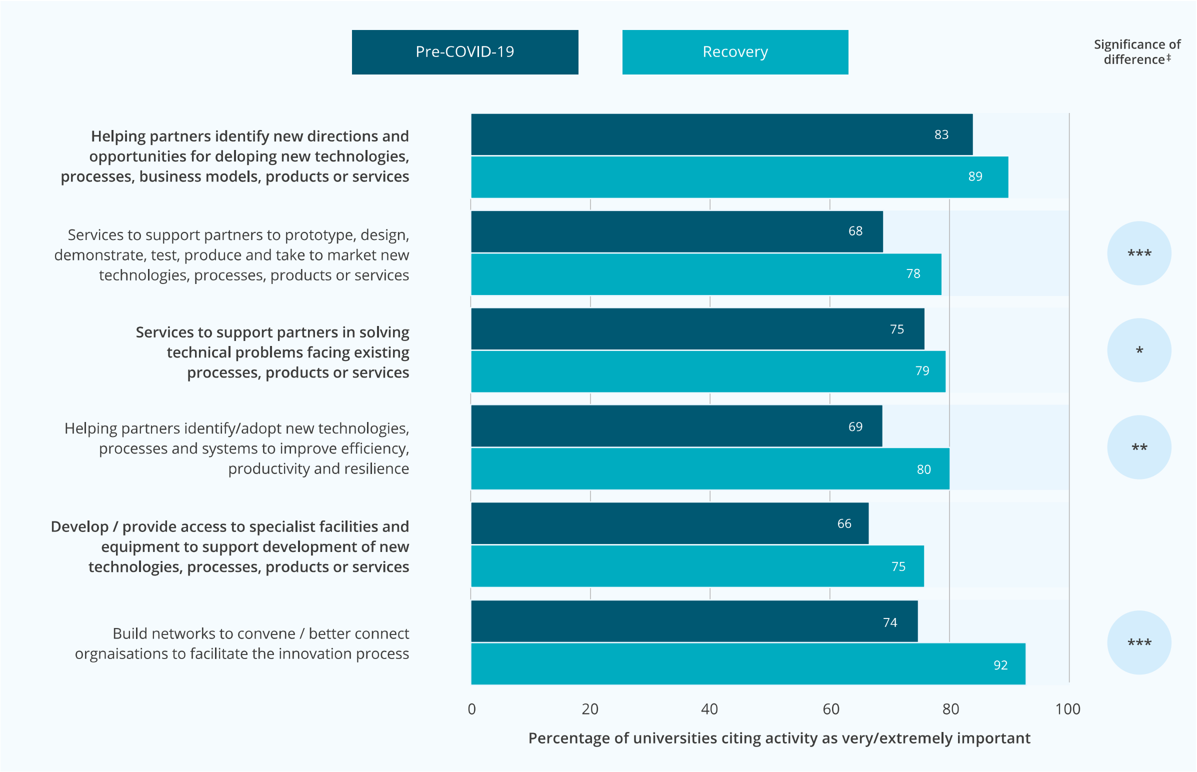
Emerging evidence suggests that UK universities are indeed beginning to adapt through the pandemic and are well-placed to meet the demands and opportunities of a more proactive innovation policy approach. A survey of 62 UK universities in August/September 2020 by UCI/NCUB (Ulrichsen, 2021) found that, in addition to a continued importance attached to basic and applied R&D post-pandemic, there is a trend towards placing increased strategic importance on challenge-led programmes that better integrate research with efforts to further develop technologies towards application (Figure 3). Further, a significant number of universities indicated that developing prototypes emerging from their research, and working to demonstrate and test them, is also of increasing strategic importance.

Figure 3| Comparing the importance placed by universities on innovation-focused R&D activities pre-Covid with expected importance for the economic recovery



‡ Statistical difference based on the paired samples Wilcoxon signed rank test. Source: (Ulrichsen, 2021).

Figure 4| Comparing the importance placed by universities on innovation-focused services and support (beyond R&D) in delivering partners' innovation objectives pre-Covid with expected importance for the economic recovery

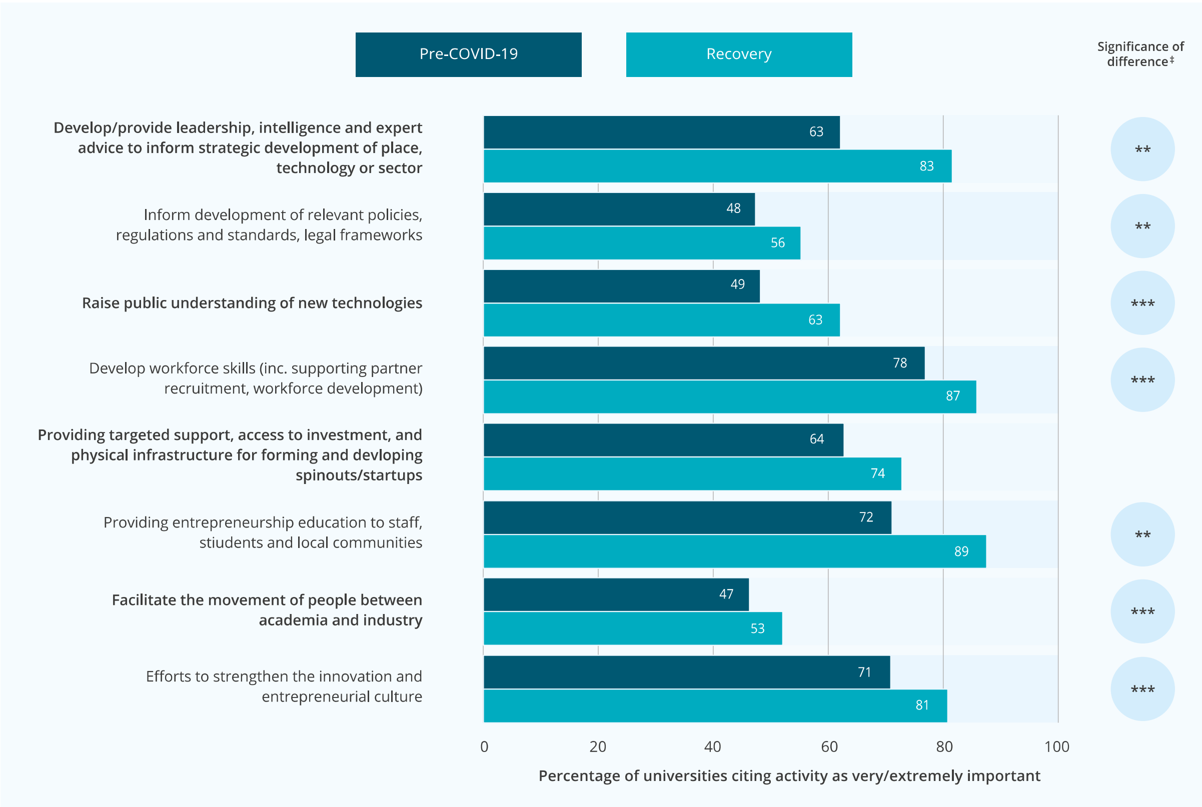


‡ Statistical difference based on the paired samples Wilcoxon signed rank test. Source: (Ulrichsen, 2021).

Moving forward, innovation policies are placing much greater emphasis on the ability of the system to not just invent new technologies, products and services, but to successfully commercialise them and diffuse them across the economy. The UCI/NCUB survey shows a growing strategic importance for universities of providing support to help partners (in the private, public and charitable sectors) with the later stages of the innovation process, such as prototyping, design, demonstration, testing, production, and taking innovations to market (Figure 4). Reflecting the growing importance of innovation diffusion, many more universities in the UK are also placing increasing strategic importance on helping their partners to identify and adopt new technologies, processes and systems to improve efficiency, productivity and resilience.

As discussed in Section 2, more modern innovation policies place a greater emphasis on strengthening the ability of the system to convene and coordinate around innovation problems and challenges. The UCI/NCUB survey suggests that, as we move into the recovery, most universities are placing significant strategic importance on building the networks to convene and better connect organisations to facilitate the innovation process (Figure 4). Further, as we move towards more proactive innovation policies, a significant growth in universities placing strategic importance in providing leadership, intelligence and expert advice to inform the strategic development of the innovation system itself (i.e. to help provide directionality) is encouraging (Figure 5).

Figure 5| Comparing the importance placed by universities on innovation system strengthening services and support pre-Covid with expected importance for the economic recovery



‡ Statistical difference based on the paired samples Wilcoxon signed rank test. Source: (Ulrichsen, 2021).

Lastly, modern innovation policies place significant importance on the strengthening of the underlying capabilities of an innovation system to better enable the development, diffusion and deployment in practice of new technologies and ideas. This includes factors well beyond R&D such as strengthening workforce skills, providing enabling innovation infrastructure, improving the culture for innovation and entrepreneurship, and strengthening the institutional framework ('rules of the game') within which innovation takes place (e.g. policies, regulations, legal frameworks etc.). As we move through the pandemic, we are seeing universities place a greater strategic emphasis on providing services and support in many of these areas (Figure 5).

Summary & conclusions

5 Summary & conclusions

In this report, we explored how innovation policies have been evolving over time and through the Covid-crisis period, focusing on the types of roles emphasised within these policies for universities and other organisations in the research base. Innovation policies need to adapt to deal with major crisis periods such as COVID, and this justifies certain policy interventions that would not normally be possible outside of such periods.

As we move into the recovery, there are also growing calls for innovation policies to not just focus on strengthening the ability of systems of innovation to innovate, but also to become much more proactive in driving 'system transformation', i.e. the managed transition to more sustainable, equitable and resilient futures. This is required to tackle other major global and national societal challenges and will require greater investments in anticipating innovation opportunities and challenges; improving the directionality of innovation activity; broadening inclusion of different stakeholders (including civil society) in the innovation process; and increasing our focus on responsible innovation.

Furthermore, we sought to capture the existing evidence base on the hugely disruptive effects of the pandemic on R&D and innovation across the economy. As innovation policy priorities change, and the effects of the pandemic become clear, universities are likely to have to adapt and reconfigure their approaches to innovation to ensure they are able to play an active and strategic role in driving an innovation-led economic recovery. With demand from key sectors of the economy and from certain types of partners (particularly SMEs) likely to be depressed for some time, universities will have to find new opportunities for productive engagements and will have to confront questions around how to maintain their capabilities to engage in partnerships and innovation.

Given the above, we believe that additional public funding is justified to enable universities to continue to deal with ongoing public health effects of the pandemic; adapt and pivot their strategic orientation and innovation-focused partnerships and activities to meet the changed needs of economies and societies post-pandemic; and finally, to maintain their R&D and innovation capabilities and infrastructure through the crisis until demand for R&D and innovation activities recovers or new opportunities are unlocked.

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Appendices

Appendix A: German High-Tech Strategy 2025 – selected initiatives

Policy instrument	Link	Lead agency	Purpose
Clusters-4Future	Link	BMBF (Federal Ministry of Education and Research)	Competitive funding process to develop powerful regional clusters in fields of innovation with high growth potential. Clusters are innovation networks that connect a critical mass of innovation-driving actors within a region along a common theme. They are designed to bring the most promising research findings to use sooner and faster.
De:Hub	Link	BMWi (Federal Ministry of Economics and Technology)	The Digital Hub Initiative supports twelve digital hubs which promote cooperation and collaboration between start-ups, established businesses and research in order to drive innovation and digitization forward
DWIH	Link	BMBF	The German Centres for Research and Innovation (DWIH) are a network of German research organisations, universities and research-based companies. In five cities around the world, the DWIH provide a joint platform for German innovation leaders, showcase the capabilities of German research and connect German researchers with local cooperation partners.
EXIST	Link	BMWi	The EXIST programme is designed to improve the start-up climate at universities and non-university research institutions and to support university graduates, scientists and students in preparing their technology-oriented and knowledge-based start-ups.
From Biology to Innovation	-	Multi agency	Interdepartmental agenda, involving industry, science and civil society, to promote research at the interfaces between scientific disciplines, as well as the development of new procedures and their applications, to further integrate biological knowledge and biotechnological and bio-inspired processes into all areas of life and economic activities
German Accelerator	Link	BMWi	The German Accelerator supports start-ups in expanding into other markets and making their business orientation more successful globally by supporting scaling of the business model for faster and strong growth, especially in the areas of market access, customer and partner acquisition, access to local networks or growth capital
GO-Bio	Link	BMBF	The funding initiative GO-Bio supports life science researchers with innovative ideas who are looking to go into business
Go-cluster	Link	BMWi	Funding programme supporting cluster management organisations with the development of their innovation cluster. Currently 84 members make use of the various offers of the programme.
IGF	Link	BMWi	The Industrial Collective Research (IGF) programme focuses on technology transfer and the implementation of research results through pre-competitive, joint research projects. A large number of companies and research institutions are grouped together in around 100 research associations that develop demand-oriented research projects and commission suitable research institutions to carry out the projects.
Industry in clinic	Link	BMBF	Funding mechanism for new innovation and cooperation models that are oriented towards medium-sized companies to strengthen the collaboration between clinicians and innovators
INNO-KOM	Link	BMWi	The Innovation Competence Funding Programme INNO-KOM supports non-profit, external, industrial research institutions in structurally weak regions to provide R&D services for SMEs in order to strengthen the innovative strength of these regions in the long term.

IPCEI	-	BMBF	Important Projects of Common European Interest (IPCEI) support further development of new products from prototype to production maturity (subject to approval by European Commission)
National AI strategy	-	Multi agency	National strategy to target the development of competencies in the area of AI
Platform for Artificial Intelligence	-	BMBF	The Plattform Lernende Systeme (Platform for Artificial Intelligence) brings together leading experts from science, business, politics and civil society organisations to discuss opportunities, challenges and framework conditions for the development and responsible use of learning systems.
r + impulse	Link	BMBF	Supports the further development and implementation of R&D results via pilot applications up to industrial reference systems or prototypes, in order to speed development towards market application from the laboratory or technical centre. Focuses on innovative technologies that lower the consumption of materials and energy in resource-intensive production systems, substitute critical raw materials, reclaim valuable resources from waste streams or utilise CO_2 as a resource.
Research campus	Link	BMBF	The Forschungscampus (Research Campus) funding initiative sets out to open up and commercially develop new highly complex fields of research with a high research risk and particular potential for quantum leap innovations. The initiative supports large-scale and long-term approaches towards single-site cooperation between science and industry, in particular SMEs
SME 4.0 competence centres	Link	BMWi	Nationwide network of 26 "Mittelstand 4.0 Competence Centres", providing a scientifically based, free, nationwide network tailored to the needs of SMEs. The competence centres inform, sensitise and qualify entrepreneurs and employees free of charge, network SMEs with one another, support the transfer of knowledge and technology to SMEs and provide concrete and practical possibilities for demonstration and testing in learning or demonstration factories.
SME-innovative	Link	BMBF	The KMU-innovativ (SME Innovative) programme supports small research-based companies in the start-up phase with equity capital.
SME-international	-	BMBF	KMU-international (SME International) programme supports SMEs to gain access to European and international cooperation and business relationships using a "2 + 2 project approach" (one company and one research institute from two countries)
SPRIN-D	Link	BMBF	Federal Agency for Disruptive Innovation, providing finance, team assembly and networking to support breakthrough innovations
Strong universities of applied sciences - impetus for the region	Link	BMBF	Grants for application-oriented research at universities of applied sciences – particularly in the engineering, natural, and economic sciences and in the social and health sciences – and innovation-oriented cooperation between the universities of applied sciences and SMEs
Transfer Initiative	-	BMBF	Programme intended to identify bottlenecks in the technology transfer process, such as regulation, financing and support, in order to help companies translate scientific research results into products and processes and encourage researchers at higher education and research institutions to engage in entrepreneurship
WIPANO	Link	BMWi	The WIPANO program supports small and medium-sized companies in protecting their intellectual property and participating in standardisation bodies
WIR!	Link	BMBF	WIR! is aimed at broad-based regional alliances of varied of actors who jointly identify fields of innovation and strengthen the region through structural change
Young Entrepreneurs in Science	Link	BMBF	Programme designed to open up new career perspectives for highly qualified, early-career researchers and channel their expert knowledge into entrepreneurial endeavours through training, mentoring and links to innovation-oriented companies
ZIM	Link	BMWi	The ZIM promotes technology and industry-open, market-oriented R&D projects by innovative medium-sized companies. The companies themselves determine how and when they implement their projects, either individually or together with national and international partners from business and / or science (cooperation projects and innovation networks).

Reference: German (pre-pandemic) High-Tech Strategy 2025 and related documents (BMBF, 2016, 2018; BMWi, 2020). All links accessed on 05 February 2022.

Appendix B: US Obama administration strategies 2009-2015 – selected initiatives

Policy instrument	Link	Lead agency	Purpose
ARPA-E	Link	Department of Energy	Establishment of the Advanced Research Projects Agency–Energy (ARPA-E), a program that accelerates innovation by investing in transformative energy technologies in order to create a more secure, affordable and sustainable energy future
Business incubators	-	Economic Development Administration	Establishment of a national network of business incubators to encourage entrepreneurial activity in economically distressed areas
Energy Innovation Hubs	Link	Department of Energy	Modelled on the proactive approach to science management exemplified by the Manhattan Project and AT&T's legendary Bell Laboratories, Energy Innovation Hubs are integrated, multidisciplinary research centres that combine basic and applied research with engineering to accelerate scientific discovery and address critical energy issues and challenges
Furnace Accelerator	Link	Department of Defense	The Accelerator is an intensive nine-month programme designed to incubate new companies that license technologies developed at the Air Force Research Lab. Furnace provides mentorship, office space, and seed funding
I-Corps	Link	National Science Foundation	The Innovation Corps (I-Corps) programme provides entrepreneurship training for Federally-funded scientists and engineers, pairing them with business mentors for an intensive curriculum focused on discovering a demand-driven path from their lab work to a marketable product. This experiential learning curriculum is based on the "Lean Launchpad" methodology developed by serial entrepreneur Steve Blank.
Innovation labs	Link	Multi agency	A network of Innovation Labs fostering a culture of innovation at Federal agencies by empowering and equipping agency employees and members of the public to implement promising ideas for improving the effectiveness and efficiency of government operations
Jobs and Innovation Accelerator	Link	Economic Development Administration	EDA's Jobs and Innovation Accelerator Challenge Initiative involved a series of multi- agency competitions that in 2011 and 2012 awarded nearly $50 million in grants. Funding was distributed to over 40 total winning consortia for cluster-building projects across a range of focus areas from advanced manufacturing to rural community clusters
Lab-to-Market	Link	Multi agency	Key mechanism of the President's Management Agenda to improve the transition of federally funded innovations from the laboratory to the marketplace by reducing the administrative and regulatory burdens for technology transfer and increasing private sector investment in later-stage research and development; develop and implement more effective partnering models and technology transfer mechanisms for Federal agencies; and enhance the effectiveness of technology transfer by improving the methods for evaluating the return on investment and economic and national security impacts of federally funded R&D, and using that information to focus efforts on approaches proven to work
Manufacturing Extension Partnership	Link	National Institute of Standards and Technology	For the past 30 years, the MEP National Network has equipped small and medium-sized manufacturers with the resources needed to grow and thrive. Industry experts work side-by-side with manufacturers to reduce costs, improve efficiencies, develop the next generation workforce, create new products, find new markets and more.
Manufacturing USA	Link	National Institute of Standards and Technology	Establishment of a nationwide network of public-private manufacturing innovation institutes that bring together companies, Federal agencies, universities, and others to develop key advanced manufacturing technologies, help businesses develop and adopt these technologies, and build a highly-skilled manufacturing workforce
MetroLab Network	Link	-	Establishment of multi-city collaborations between city leaders, universities and industry, to undertake smart city projects and share best practices

National initiatives (nanotechnology, robotics, strategic computing, genomics, big data)	-	Multi agency	National strategies, executed in collaboration with industry and academia, to spur the creation and deployment of emerging technologies at the leading edge, helping to advance Administration priorities for economic competitiveness, scientific discovery, and national security
NCAI & REACH	Link	National Institute of Health	Centres for Accelerated Innovations (NCAI) and Research Evaluation and Commercialization Hubs (REACH) are public-private partnerships with expertise and resources from the federal government, academia, and the private-sector, designed to accelerate translation of scientific discovery into commercial products that improve health for patients
NIH High Risk-High Reward Research	Link	National Institute of Health	Funding mechanisms to support high-risk, high-return research
NIICE	Link	Department of Energy	The National Incubator Initiative for Clean Energy (NIICE) programme to fund up to five specialised business incubators that help entrepreneurs commercialise clean-energy technologies.
NITRD	Link	Multiple agencies	The Networking and Information Technology Research and Development (NITRD) Program funds research in areas such as high-speed networks, next-generation supercomputers, cyber-physical systems, software engineering, and information management
Regional Clusters	Link	Small Business Administration	Establishment of a programme to harness the potential of regional clusters to drive economic growth, create jobs, and strengthen American competitiveness
Regional Innovation Accelerator Network	Link	Economic Development Administration	Establishment of a programme to support a virtual nationwide community of organisations that promote regional growth by promoting commercialisation and the development of new high-growth firms.
Regional Innovation Strategies	Link	Economic Development Administration	Establishment of a programme to promote innovation-based, high-growth entrepreneurship in pursuit of job creation and economic growth and support efforts to commercialise technology developed through university and federally-funded research, such as proof of concept centres
SBIR	Link	Small Business Administration	The Small Business Innovation Research (SBIR) programme is a highly competitive programme that encourage domestic small businesses to engage in Federal Research/Research and Development with the potential for commercialisation.
SHARP	Link	National Institute of Health	The Strategic Health IT Advanced Research Projects (SHARP) Programme funds potentially game-changing advances to address well-documented problems that have impeded adoption of health IT
Small Business Vouchers	Link	Small Business Administration	Pilot programme across several National Labs to provide vouchers to small businesses. These vouchers, redeemable for technical assistance at participating Labs, are targeted at those small businesses developing promising clean-energy technologies
Space Technology Mission Directorate	Link	National Aeronautics and Space Administration	The creation of the Space Technology Mission Directorate is allowing NASA to invest in breakthrough technologies
SSBCI	Link	Department of the Treasury	Treasury's State Small Business Credit Initiative (SSBCI) has allocated $1.5 billion to state programs that support innovative small businesses
Startup America	Link	White House	Establishment of an initiative to accelerate and incentivise the transfer of research breakthroughs from university labs, including through early-stage seed financing and other investments in high-growth startups; improving the regulatory environment for starting and growing new businesses; and increasing connections between entrepreneurs and high-quality business mentors
STTR	Link	Small Business Administration	The Small Business Technology Transfer (STTR) programme is a highly competitive programme that encourage domestic small businesses to engage in Federal Research/Research and Development with the potential for commercialisation via partnerships with non-profit research institutions

Reference: Obama administration pre-pandemic innovation strategies (EOP, NEC and OSTP, 2009; NEC, CEA and OSTP, 2011; NEC and OSTP, 2015). All links accessed on 05 February 2022.

Appendix C: US Innovation and Competition Act (2021) – selected initiatives

Policy instrument	Budgetary provision (FY2022-2026, billion USD)	Lead agency	Purpose
NSF appropriations *Of which:*	81.0	NSF (National Science Foundation)	Total NSF appropriations which include specific named allocations listed below
STEM education and related activities, including workforce activities	17.43	NSF	Establishment of programmes to develop research capacity at eligible institutions and STEM competencies in the current and future workforce
Chief Diversity Officer	-	NSF	Appointment of a Chief Diversity Officer for the NSF
Directorate For Technology And Innovation *Of which:*	29.0	NSF	Establishment of the NSF Directorate For Technology And Innovation
University technology centres and innovation institutes	9.57	NSF	Establishment of a programme to make awards to enable eligible entities to establish university technology centres and institutes of innovation
Scholarships, fellowships, and student support	5.22	NSF	Funding for undergraduate scholarships, graduate fellowships and traineeships, and postdoctoral awards in the key technology focus areas
Academic technology transfer	4.06		Funding awards, in coordination with the National Institute of Standards and Technology and other Federal agencies, to eligible entities to advance the development and commercialisation of technologies, particularly those in the key technology focus areas.
Test beds	2.90	NSF	Establishment of a programme in the Directorate, in coordination with the National Institute of Standards and Technology, the Secretary of Energy, and other Federal agencies, to institutions of higher education, non-profit organisations, or consortia to establish and operate test beds, which may include fabrication facilities and cyberinfrastructure, to advance the development, operation, integration, deployment, and demonstration of new, innovative technologies in the key technology focus areas, which may include hardware or software.
R&D activities	4.35	NSF	Funding awards for research and technology development within the key technology focus areas
Collaborative activities	2.90	NSF	Collaboration between the Directorate and other directorates and offices of the Foundation
DoE appropriations	16.90	DoE (Department of Energy)	Appropriations to carry out R&D and address energy-related supply chain activities within key technology focus areas

DARPA appropriations	17.50	DoD (Department of Defense)	Appropriations to carry out R&D in key technology focus areas
Regional technology hubs	10.00	DoC	Establishment of a programme to encourage new and constructive collaboration among local, State, and Federal government entities, academia, the private sector, economic development organisations, and labour organisations; to support eligible consortia in the creation and implementation of regional innovation strategies (designated 'regional technology hubs')
Hollings Manufacturing Extension Partnership (MEP)	2.40	NIST (National Institute of Standards and Technology)	Appropriations to cover base funding of the MEP and to establish a programme of expansion awards to support the mission of the MEP
Manufacturing USA	6.00	NIST	Expansion of the Manufacturing USA programme to support innovation and growth in domestic manufacturing
National Manufacturing Advisory Council	-	DoC (Department of Commerce)	Establishment within the Department of Commerce of the National Manufacturing Advisory Council to support US domestic manufacturing
Office of Manufacturing & Industrial Innovation Policy	0.05	Executive Office of the President	Establishment of an Office of Manufacturing and Industrial Innovation Policy to advise the President on manufacturing and industrial innovation considerations relating to areas of national concern

Reference: US Innovation and Competition Act or USICA (US Congress, 2021, sections 2102-2522)

Appendix D: Coding frame

Policy theme	Types of instruments
Research to unlock innovative applications	Promotion of high-risk/high reward research
	Promotion of internationalisation in public research
	Promotion of interdisciplinary research
	Strategies, roadmaps or plans to provide strategic direction to national research policy
	Support for open science /data
Commercialisation and tech transfer (development, prototyping, demonstration & test, industrialisation/scale-up, knowledge transfer)	Promotion of collaboration and co-creation for R&D and innovation
	Strategies or plans to direct national/regional policy on knowledge transfer and linkages
	Encouraging commercialisation of public research results
	Encouraging mobility of human resources between the public and private sectors
System governance and strategic direction	Creation or reform of governance structure or public body
	Horizontal policy coordination arrangements
	Regulatory oversight and ethical advice bodies
	Formal consultation of stakeholders or experts
	Arrangements for evaluation and impact assessment
	Standards and certification for technology development and adoption
	Strategies or plans to provide an overarching strategic direction to national STI policy
	Strategic policy intelligence arrangements
Stimulating demand	Targeted support for SMEs R&D and innovation
	Targeted support for young innovative enterprises & start-ups R&D and innovation
	Strategies or plans to strategically direct national policy on business innovation and/or innovative entrepreneurship
	Initiatives to stimulate demand for firms' innovations and to support market creating innovation
	Procurement programmes for R&D and innovation
Productivity, innovation adoption and diffusion	Arrangements to diffuse innovations
	Activities to develop/grow businesses
	Technology extension and business advisory services
	Digital transformation of firms
Talent / workforce development	Job creation
	Development of STEM skills
	Non-financial support for doctoral and postdoctoral researchers
	Building digital skills for researchers
	Promoting inclusiveness for women and other under-represented groups in R&D and innovation
	National strategies or plans to foster human resources for research and innovation
	Fellowships and postgraduate loans and scholarships
	Jobseeker-industry matching
Other framework conditions	Access to finance for R&D and Innovation (including competitive funding for R&D, follow-on-funding, equity financing etc.)
	Entrepreneurial capability
	Networks
	Infrastructure (physical, financial, communications, transport etc.)
	Institutions (e.g. tax, legal, IP, other policy, standards, regulations, culture etc.)
	Access to markets
Research and innovation for society	Promotion of a broad and diversified public engagement in research and innovation activities and policy making
	Raising awareness in science, technology and innovation activities across society at large
	Strategies or plans to promote innovation for societal well-being and cohesion

Appendix E: Content analysis of innovation strategies

Dimension of proactive strategy	Key word/phrase	Obama 2009	Obama 2011	Obama 2015	USICA
Enhanced anticipation of innovation's collateral effects and consequences through generating multiple development paths, identifying the most desirable paths through societal experimentation and examining possible consequences of these paths	Technology assessment	0	0	0	1
	Foresight	0	0	0	2
	Horizon scanning/new horizons	0	0	2	0
	Vision assessment	6	7	24	3
	Scenario planning	0	0	0	0
	Total	**6**	**7**	**26**	**6**
Improved directionality through taking into account a broad range of views concerning a range of possible development paths, challenging incumbents' views, and finally narrowing in on a limited number of acceptable paths and their connections to societal goals	Key technologies/Key enabling technologies/emerging science, technologies or sectors	3	6	19	82
	Challenges (grand, technology, national/regional/local, sectoral, social)	12	33	78	64
	Mission (e.g. mission-oriented, mission of national need)	0	0	13	131
	Breakthrough	8	32	52	1
	High risk-High reward/return (research)	3	0	5	1
	Advanced research	0	9	9	6
	Frontier (science/technology)	1	2	8	12
	Priorities (e.g. national priorities, thematic priorities)	5	20	44	35
	Key technology focus area: AI, machine learning & autonomy	0	0	11	73
	Key technology focus area: High performance computing, semiconductors, and advanced computer hardware and software	6	8	20	63
	Key technology focus area: Quantum information science and technology	1	6	0	63
	Key technology focus area: Robotics, automation, and advanced manufacturing	2	25	20	21
	Key technology focus area: Natural and anthropogenic disaster prevention or mitigation	0	0	0	1
	Key technology focus area: Advanced communications technology and immersive technology	1	0	1	2
	Key technology focus area: Biotechnology, medical technology, genomics, synthetic biology	5	26	17	18
	Key technology focus area: Data storage, data management, distributed ledger technologies, and cybersecurity, including biometrics	2	6	10	52
	Key technology focus area: Advanced energy and industrial efficiency technologies, such as batteries and advanced nuclear technologies	39	88	48	85
	Key technology focus area: Advanced materials science, including composites and 2D materials	4	1	4	46
	Other advanced technology areas of focus (e.g. vehicles, education)	12	19	16	27
	Total	**104**	**281**	**375**	**783**

Broadened inclusion in terms of both participation in innovation processes (e.g. by industry, the social sciences and humanities, international researchers, civil society and the public) and ensuring a more equitable distribution of innovation benefits	Broaden (e.g. broaden the innovation base, broaden innovation, broaden participation, broaden the circle of opportunities)	6	9	19	17
	Inclusion/inclusive	0	0	4	12
	Diversity	1	3	2	45
	Open science	0	0	0	0
	Open data	0	0	5	2
	Interdisciplinary/multidisciplinary/ transdisciplinary	3	2	2	22
	Open innovation	0	0	9	0
	Public-private (partnership)	0	7	6	19
	Public platform	0	0	0	0
	Citizen participation/science	1	1	35	1
	Crowdsourcing	0	0	25	0
	User-centred design (leading edge users, specifically designed for users, partnerships with other users, user facility, bring science and industry together with users)	0	3	22	8
	Civil society (participation in innovation)	2	0	2	6
	Public input/outreach	0	0	0	24
	Convening	2	3	3	15
	Network (i.e. innovation/entrepreneurship network)	2	3	13	20
	Cluster	2	23	10	0
	Regional/regions (e.g. regional technology hubs, regional development strategy)	3	34	22	114
	Place-based	0	0	1	1
	Shared prosperity	2	0	6	0
	Total	0	0	25	0
Increased deliberation, involving an iterative exchange of views, which in turn requires enhancing societal capacities to understand, communicate on and shape technology through the course of development so that technology might advance under conditions of trust	Dialogue	0	0	0	2
	Critical reflection/reflexive	0	0	0	0
	Consensus conference	0	0	0	4
	Moratorium	0	0	0	1
	Citizens' jury	0	0	0	0
	Deliberative mapping/ polling	0	0	0	0
	Focus group	0	0	0	1
	Agenda-setting	1	3	11	1
	Strategy/strategic vision	22	57	44	103
	Technology roadmapping	0	4	0	3
	Total	**23**	**64**	**55**	**115**
Responsible innovation through encouraging an ethical, anticipatory and reflexive approach from the private sector, particularly for emerging technologies.	Responsible (e.g. responsible innovation/economic development)	0	0	1	17
	Ethical/ethics	0	0	1	14
	Code of conduct	0	0	0	4
	Total	**0**	**0**	**2**	**35**

Note: Content analysis performed using an approach based on that of Short et al.(2010), using (Stilgoe, Owen and Macnaghten, 2013) to generate *a priori* codes. Innovation strategies tested: Obama administration strategy 2009 (EOP, NEC and OSTP, 2009), Obama administration strategy 2011 (NEC, CEA and OSTP, 2011), Obama administration strategy 2015 (NEC and OSTP, 2015), USICA (US Congress, 2021).

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