INDÚSTRIA 2027

Riscos e oportunidades para o Brasil
diante de inovações disruptivas

PRODUTO 4

POSITION PAPER

ESPECIALISTA INTERNACIONAL
University of Cambridge

Março de 2018

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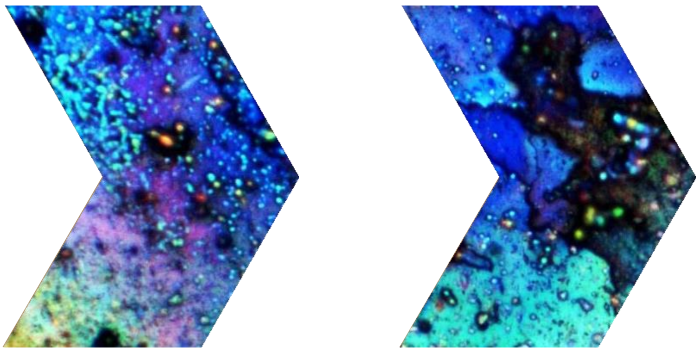
A review of international approaches to industrial innovation: lessons to inform Brazil's "I2027" strategy

A report for the Brazilian Industrial Board (CNI)

March 2018



About this report

The Brazilian Industrial Board (*Confederação Nacional da Indústria*, CNI) has commissioned the Institute of Economics, Federal University of Rio de Janeiro and the Institute of Economics, University of Campinas (UNICAMP) to undertake the project "Industry 2027 and Disruptive Innovations: Risks and Opportunities for Brazil" (I2027).

To inform this project, Policy Links, IfM Education and Consultancy Services (IfM ECS), University of Cambridge, has carried out this review of international policy approaches to supporting the generation, absorption and diffusion of advanced technologies in industry.

The authors of this report are Carlos López-Gómez, Michele Palladino and David Leal-Ayala. Eoin O'Sullivan provided academic guidance and useful comments, and Jennifer Castaneda and Paulo Savaget provided research assistance. The team received valuable guidance from the I2027 project team.

Executive summary

The aim of this study is to help identify the policy implications for Brazil arising from the impact of disruptive technologies on national industries. The report is based on an international review of programmes, mechanisms and initiatives put in place to support the generation, diffusion and deployment of advanced technologies in industry.

Five opportunity areas for effective policy design and implementation have been selected as being particularly relevant for the purposes of the project "*Industry 2027 and Disruptive Innovations: Risks and Opportunities for Brazil (I2027)*". While the Policy Links study team did not join the I2027 project from the start, the five opportunity areas explored in this study were selected under the guidance of the I2027's project team taking into consideration emerging findings from their work. Another key source of validation were inputs from key stakeholders collected during the workshop "*Políticas públicas internacionais para tecnologias disruptivas e apresentação dos resultados da pesquisa do Projeto Indústria 2027*", organised in Brasilia in December 2017, in the framework of the 19º *Diálogos da MEI*.

An initial list comprising over sixty international programmes was reviewed and, from these, twelve cases were selected for further analysis. The selected case studies include programmes from China, Denmark, Germany, Ireland, Singapore, Sweden and the United States.

The five opportunity areas for effective policy design and implementation that appear particularly relevant to Brazil are as follows:

- **Agency coordination and formation of a common national vision around new technologies.** Many of the challenges related to the development, diffusion and deployment of emerging technologies are systemic in nature. Technologies may have a cross-cutting impact in a wide range of industries and firms. Internationally, there is increasing emphasis on the need to enhance the coordination of actors, networks and institutions. This includes better integrating technical expertise, and research and development infrastructure in order to promote innovation more effectively. Programmes and institutions that facilitate close interaction and sharing of insights between laboratory-based researchers, manufacturing engineers, equipment manufacturers, and user industries, are receiving increasing attention. Examples of international efforts to create national frameworks of cooperation and communication, include the creation of inter-agency working groups (to provide visibility of how individual efforts contribute to national goals), the publication of national technology plans (to ensure synergies between sources funding similar technology domains), and the establishment of coordination functions in national innovation agencies (to provide foster linkages and provide national visions).

- **Scale-up and "manufacturability" of emerging technologies.** Ensuring that advances in technology made in a laboratory make their way into industrial applications is fraught with challenges. The path to successful commercialisation requires that technologies function well at large scale, and that the products are produced at industrial scale. Internationally, a central concern for governments is the design of institutions, programmes and initiatives aimed at ensuring that research output is developed, demonstrated and deployed in industry. One key driver is the need to ensure "value for money". There is increased pressure from central governments and treasury departments to ensure that, in times of budget constraints, countries are able to capture value from their investments in science and innovation. The review of the international experience reveals that a number of countries are stepping up investments in applied research centres and pilot production facilities focused on taking innovations out of laboratories and into production increasing recognition that technology scale-up from concept to reality. There is increasing recognition that the scale up and 'manufacturability' of emerging technologies requires the right combination of tools and facilities, such as advanced metrology, real-time monitoring technologies, analysis and testing, shared databases, and modelling and simulation tools. This includes demonstration facilities such as test beds, pilot lines and factory demonstrators that provide dedicated research environments with the right mix of tools and enabling technologies, and the technicians to operate them.

- **SME capability-building.** Many firms, in particular small and medium-sized enterprises (SMEs), are unable to exploit the opportunities offered by new technologies. Even when those technologies are readily available in the market, firms fail to take advantage of them to update their products and processes. Internationally, there seems to be increasing recognition that the effectiveness of efforts to build SMEs capability is affected by the extent to which support institutions are spread across regions in the country, the network of other actors these institutions partner with, and the number of firms that they are able to engage with. The international experience also reveals that policy efforts to support SME capability go beyond R&D, ranging from "soft support" (such as the provision of information and support to create industrial networks around common interests) to "hard support" (hands-on support through activities such as training, contract research and expert advice). Some of the programmes analysed, for example, offer firms the possibility to access a range of consultancy services ranging from human resources and financial management to technical solutions development. Such services are provided by qualified providers, such as universities and research centres spread across countries. Another example is the support for the technological upgrading of SMEs by promoting the secondment of research scientists and engineers to local firms through government-supported industry attachment programmes.

- **R&D collaborative networks.** Not all firms have the capabilities to engage in R&D. A large proportion of firms do not have the time, capacity or funds to partner with universities or research organisations. The lack of engagement of firms in R&D and innovative activities represents a risk to long-term competitiveness in advanced industries that require continuous innovation. The international experience reveals increased policy attention to the promotion of collaboration among firms and institutions through R&D networks. This responds to a number of needs: engaging more firms in R&D (including SMEs), forming multidisciplinary teams, ensuring aligned investments in technology areas that depend on one another, and ensuring critical mass by bringing together financial resources. All too often, progress in advancing the functionality of new application technologies and efforts to enhance the functionality of novel production technologies are carried out in isolation. However, advances in technology may have an impact in different sectors and, as such, R&D networks can help to exploit opportunities for collaboration among sectors. The review also shows the importance of industrial networks, involving SMEs and large firms, for eliciting information about national opportunity areas. Such networks can help to identify the areas where policy action might be required. Some of the programmes analysed are specifically focused on building stronger cooperation between small firms and large companies by funding collaborative projects. Similarly, some of these programmes provide SMEs with limited engagement in R&D practical support in the tasks of articulating relevant projects, and identifying partners and sources of funding.

- **Skills development in disruptive technologies.** The deployment of key enabling technologies can lead to significant benefits in terms of productivity and economic growth. However, in order to tap into the potential of emerging technological trends, it is critical to nurture skills and education and training systems at a pace that matches that of technological diffusion. In this respect, skills are given central importance in national policy agendas around the world, given that advances in new technologies require workers with new multidisciplinary competencies, combining different types of knowledge and skills. Although the overall impact of digital technologies on employment in terms of displaced jobs and net job creation is still under debate, emerging technologies are likely to displace manual repetitive jobs, while creating new jobs that would demand new skills. These trends impose challenges on both employees and employers. Efforts are being made by governments to implement comprehensive strategies for skills development, including awareness-raising, mentoring and training on digital skills for different career stages. Collaboration between public research centres and industry has led, for example, to the definition of industry-led curricula focusing on engineering subjects and the creation of skills development programmes based on the replication of state-of-the-art manufacturing facilities to provide the right environment for quality training. In addition, new vocational training programmes are being created, designed around emerging technologies and adapted to the particular needs of SMEs.

While the set of opportunity areas discussed in this report is by no means exhaustive, it does highlight key areas where policy efforts can have a significant impact in enhancing Brazil's innovation performance. Additional opportunity areas may be relevant, however, for supporting industrial innovation in Brazil, and might require further analysis. What the project does is showcase an analytical approach that could be replicated for other areas.

Further analysis may be required to fully assess the innovation constraints of the Brazilian economic system in order to identify additional relevant opportunity areas for policy design and implementation. Additional in-depth analysis might also be required to improve the understanding of contextual factors underpinning the effectiveness of particular approaches adopted in other countries. Further work to compare and contrast approaches to programme evaluation is required.

Finally, it is important to note that the report presents only a small selection of case studies, which are not put forward as suggestions regarding particular approaches that Brazil should adopt. Instead, they have been selected because they illustrate a variety of policy approaches, addressing opportunity areas that are of relevance to Brazil, which can stimulate debate and inform policy thinking in the country. They also provide a useful context for what international competitors are doing.

To conclude, the report highlights that the ability of nations to translate new technologies into high-value production within their economies depends on how the science and engineering base is integrated in the domestic industrial system. A weak connection between science and industry could constrain the potential of new technologies and the economy's ability to innovate the next generation of high-value manufacturing products. To compete effectively, therefore, national economies require industrial systems that can respond to emerging high-value industrial opportunities with the right combinations and clusters of technological R&D, skills, institutions and infrastructure.

TABLE OF CONTENTS

1

Introduction

This report presents an international review of programmes, mechanisms and initiatives aimed at supporting industrial innovation. The report seeks to inform the ongoing project *Industry 2027 and Disruptive Innovations: Risks and Opportunities for Brazil* (I2027), paying particular attention to contrasting international approaches to supporting the generation, absorption and diffusion of advanced technologies in industry. Efforts are made to highlight insights that are of particular relevance to Brazil.

It is important to highlight that this report constitutes only part of the input of a wider initiative of the I2027 team to inform policy design in Brazil. While this selection of case studies is by no means exhaustive, it does provide a valuable international background to policy discussions in Brazil. The cases presented showcase some of the most recent practical attempts to exploit the potential benefits of disruptive technologies in industry and the economy more widely. They also provide relevant insights into the actions that competitor countries are taking to support innovation and competitiveness.

The aims of the I2027 project have been defined as follows:

- To identify key technologies and evaluate their impact on different production systems over a five- to ten-year horizon;
- To assess business awareness and responsiveness to innovation challenges and to define requirements to move forwards;
- To evaluate Brazil's ability to deflect risks, monitor, absorb and take advantage of disruptive innovations; and
- To subsidise the formulation of public policies for the construction of a catching-up strategy.

The I2027 project identified eight key technology clusters: 1) ICTs: cloud computing, big data, artificial intelligence (AI); 2) ICTs: networks; 3) ICTs: the Internet of things (IoT) systems and equipment; 4) intelligent and connected production; 5) energy storage; 6) new materials; 7) nanotechnologies; and 8) bioprocesses and advanced biotechnologies. The impact of these technological innovations was assessed focusing on specific productive systems, namely: agro-industries; basic industries; chemicals; oil and gas; capital goods; automotive; aerospace/defence; ICTs; pharmaceuticals; and consumer goods.

Against this backdrop, the aim of this study is to help identify the policy implications and challenges for Brazil that are associated with such disruptive technologies. The review and synthesis of the work previously conducted in the context of the I2027, and consultations with the I2027's project team, have led to the identification of five opportunity areas for effective policy design and implementation that are particularly relevant to this project:

1. Agency coordination and formation of a common national vision around new technologies;
2. Scale-up and "manufacturability" of emerging technologies;
3. SME capability-building;
4. R&D collaborative networks;
5. Skills development in disruptive technologies.

A selection of case studies was conducted to illustrate how governments across the world are addressing the five opportunity areas defined above. Twelve international programmes were selected under the guidance of the I2027 delivery team. These were shortlisted from a long list comprising over sixty programmes. The 12 selected international approaches were benchmarked by analysing the *why* (i.e. the policy rationale behind the establishment of programmes), the *what* (i.e. the programmes' target and/or focus), the *how* (i.e. the types of support offered and policy instruments being mobilised) and the *who* (i.e. the level of involvement of public organisations at central or regional level, and private institutions).

The comparative analysis of the selected international approaches seeks to inform the design of policies to support industrial innovation in Brazil. It is worth mentioning, however, that a number of policy areas are not covered in the case studies, including: university research centres, cluster programmes and vocational education, among others. Similarly, the report has not attempted to provide a diagnosis of the main issues that need to be addressed in Brazil, or to indicate which institutions or actors should be responsible for specific actions. Given the scope of the project, only a few representative case studies, selected in consultation with the I2027 delivery team, are presented in this report.

Sources of information

Policy Links / IfM ECS, University of Cambridge, has a long-standing experience in monitoring, analysing and comparing policy practices in both emerging and industrialised countries. The main sources of knowledge and evidence for this report have been publicly available information on selected programmes, mechanisms and initiatives aimed at supporting industrial innovation in selected countries from around the world, structured and analysed using Policy Links' expert knowledge. This includes secondary sources such as programme websites, annual reports, strategy documents, positioning papers, and, when available, evaluation studies.

The reminder of this report is structured as follows:

- **Section 2** discusses the opportunity areas defining the scope for government intervention to support the generation, absorption and diffusion of advanced technologies that are relevant for the Brazilian industry.
- **Section 3** focuses on a review of 12 international case studies on how governments across the world are addressing the challenges and opportunities associated with disruptive technologies.
- **Section 4** conducts a comparative analysis of the selected case studies that will help to inform policy implications for Brazil.

2

Opportunity areas for effective policy design and implementation

The aim of this section is to discuss the opportunities and challenges of reaping the potential benefits of disruptive technologies in industry and society. It also discusses the type of policy approaches that might support the generation, absorption and diffusion of advanced technologies from a conceptual perspective. Insights emerging from this section are later used as selection criteria for the review of international case studies relevant to the Brazilian industries and institutional context.

Five opportunity areas that appear to be particularly relevant to Brazil were identified following consultations with the I2027's project team, and the review of the preliminary findings of the I2027 project.

These areas include:

1. Agency coordination and formation of a common national vision around new technologies;
2. Scale-up and "manufacturability" of emerging technologies;
3. SME capability-building;
4. R&D collaborative networks;
5. Skills development in disruptive technologies.

2.1 Agency coordination and formation of a common national vision around new technologies

Key points of this section

- Given the multidisciplinary nature of many of the challenges associated with the development of new technologies, bringing together expertise in different technological domains and research disciplines seems critical.
- Many technological challenges require combined investments and efforts from multiple government agencies, and from the private sector, to ensure critical mass.
- The potential impact and future directions of emerging technologies are uncertain, which makes it difficult for the variety of relevant actors to agree on common visions, priorities and actions.
- Governments often encounter challenges in trying to reconcile a mix of policy goals with the needs of different public bodies and the objectives of their agendas.
- A number of actors and institutions are relevant for effective innovation, but long-term planning and the coordinated delivery of policy support can be difficult to achieve.

Overview

Many of the challenges related to the development, diffusion and deployment of emerging technologies are systemic in nature.[1] Effective policy development and implementation thus require the coordination of relevant actors, networks and institutions.[2] Innovation – including not just basic science and R&D, but also the deployment of new technologies into actual applications and production processes – involves complex interactions between research centres and universities, private agents, and science and technology policies .[3]

It has been widely recognised that, among the lack of clearly defined objectives, guiding the integration of efforts by diverse agents and policies is one of the main shortcomings of innovation systems in many countries. Brazil is no exception. Coherence, continuity and coordination of policies and agents are critical to boosting the generation, diffusion and deployment of emerging technologies. In this context, opportunities have been identified for Brazil to improve the coordination of policies and agents around a national vision to steer industrial progress towards more "desirable social and economic directions".[4]

This section discusses the challenges and opportunities related to the following issues:

- **Providing a common vision around new technologies and their potential impact;**
- **Coordinating policies to more effectively address the challenges and opportunities related to new technologies;**
- **Coordinating the actors involved in designing and implementing these policies.**

Providing a common vision around new technologies and their potential impact

Many of the technical challenges involved in the development, deployment and diffusion of new technologies are multidisciplinary in nature. While the potential impact of individual technologies is receiving significant attention internationally, it is their integration with other technologies and systems that makes their impact so potentially disruptive. Furthermore, many of these technologies are expected to have a cross-cutting impact, opening up possibilities for a wide range of industries and firms.

> ***Many of the challenges related to the development, diffusion and deployment of new emerging technologies are systemic in nature…***

[1] Systems can be seen as "hierarchical structures, composed by subsystems and their respective components, which are interconnected in seamless webs and delivering a set of functions". Source: Meadows, D. (2008). *Thinking in Systems: A Primer*.
[2] Malerba, F. (2004). *Sectoral systems of innovation: concepts, issues and analyses of six major sectors in Europe*. Cambridge University Press.
[3] Lundvall, B.-Å., Johnson, B., Andersen, E. S., & Dalum, B. (2002). National systems of production, innovation and competence building. *Research Policy*, 31(2), 213–231.
[4] IPEA (2009). Desafios da Real Política Industrial Brasileira do Século XXI.

Defining a "national vision" can help to navigate the complexity and uncertainty of emerging technological and industrial systems…

As such, a common "national vision" about the future of technologies and their potential impact can help firms to understand them better, to demystify their potential impact and coordinate efforts.

Development goals[5] and steering mechanisms of innovation systems should, ideally, be socially negotiated through plural appraisal and deliberation, and actions coordinated among a vast array of agents continuously adapting to changes in their respective contexts. However, social perceptions of the current state of affairs and expectations of desirable and viable futures are essentially plural. There are multiple public understandings about how changes can, and should, be carried out. In other words, the consequences of any technological innovation should not be viewed as benefits to isolated groups or selected organisations, but rather assessed in terms of their full economic, social and environmental impact on society at large.[6]

As a consequence, democratic appraisal towards the inclusion of a variety of potential pathways for socio-technical progress is not merely desirable but also reflects with greater accuracy the multilevel and multifaceted character of reality.[7] In this respect, democratic and deliberative policy-making acknowledges plurality within human intentionality and also becomes a key pillar for rigorous evaluation and accountability of the pathways chosen.

Moreover, several agents influence system change, but none are fully responsible, nor accountable, for them. Democratic appraisal can thus open up a variety of potential pathways for deliberation. Not only is this desirable, but it also reflects more accurately the multifaceted nature of social and technological development.[8]

There are several tools to assist in the appraisal and deliberation of technological futures; among them is multi-criteria mapping,[9] which assists the process of portraying multiple perspectives on key issues and their potential responses. Undoubtedly, different aspects are to be prioritised in the design and coordination of a wide array of policies.

National forward-looking White Papers, foresighting exercises, technology roadmaps and similar exercises can help to disseminate the insights of new technologies and to build a consensual vision for the key innovation actors – from academia, industry, the government and the general public.[10] Such information-sharing exercises may involve or guide the design and coordination of a wide array of policies.

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[5] In this context, the definition of development refers to the transition from one state to another.
[6] UNCTAD (1999). A framework for a common vision for the future contribution of science and technology for development: elements of change and possible responses.
[7] Savaget, P., & Acero, L. (2017). Plurality in understandings of innovation, socio-technical progress and sustainable development: an analysis of OECD expert narratives. Public Understanding of Science.
[8] Stirling, A. (2008). Opening up and Closing down: Power, participation, and pluralism in the social appraisal of technology, 33(2), 262–294.
[9] Available at: http://www.multicriteriamapping.com/
[10] Eames, M., & McDowall, W. (2010). Sustainability, foresight and contested futures: exploring visions and pathways in the transition to a hydrogen economy. *Technology Analysis & Strategic Management*, 22(6), 671–692.

Not all perspectives can be incorporated into all political decisions. However, in inclusive, participatory decision-making, plural perspectives can be assessed, and the process of inclusion or exclusion of options can be made explicit, discussed and justified.[11] By providing a common vision, the country can adopt an agile and adaptable governance approach to leverage opportunities arising across different regional and technological contexts, and tapping into emerging trends to pursue national goals.

The experiences of countries as diverse as the United States, Japan and South Korea have signalled the importance of the state in providing a framework for bringing together policies and institutions. It is also argued that highly innovative smaller countries, such as Singapore and Finland, find it easier to cultivate a sense of national mission where technological innovation is concerned, especially if they have consensual politics or a strong government.[12]

At a time of fast-paced social and technological change, combined with growing global interdependence, some argue that there is an increasing need for governments to indicate the way forwards, to coordinate and to act as catalysers of system change.[13]

Coordinating policies addressing the challenges arising from new technologies

Coordination is challenging and governments often encounter a mix of imperatives when seeking to coordinate different ministries and agencies as part of wider initiatives to improve policy coherence across governmental organisations.[14] Deliberate intents of transforming technological development and uptake are not the purviews of single actors. They are, instead, collective endeavours requiring coordinated action to align different interests towards common goals.

There is a need to acknowledge the limitations of what can realistically be achieved in terms of policy coherence…

Different agents can, nonetheless, assume dominant roles to influence, manage or govern wide-scale changes.[15] Policies and regulations also tend to favour short-term incentives, instead of coordinated, long-term planning. In this regard, it is important to acknowledge the limitations of what can realistically be achieved in terms of policy coherence,[16] while simultaneously recognising what is needed to govern in pluralistic and multi-actor political systems.

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[11] Savaget, P., & Acero, L. (2017). Plurality in understandings of innovation, socio-technical progress and sustainable development: an analysis of OECD expert narratives. Public Understanding of Science.
[12] Rae J., & Westlake S. (2014). When small is beautiful – lessons from highly innovative smaller countries. Nesta.
[13] UNCTAD (1999). A framework for a common vision for the future contribution of science and technology for development: elements of change and possible responses.
[14] Suzigan, Wilson, & Furtado, João. (2010). Instituições e políticas industriais e tecnológicas: reflexões a partir da experiência brasileira. *Estudos Econômicos* (São Paulo), 40(1), 7–41.
[15] Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), 1257–1274.
[16] OECD (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.

Against this backdrop, the design and effective implementation of technology strategies may be influenced by:

- The institutional and regulatory framework at federal, regional and municipal levels;
- The expected outcomes that the strategy aims to achieve;
- The impact of policies on each stakeholder;
- The pressures of influential stakeholders, shaping prioritised sectors and policies.

The pursuit of national strategies involves a variety of incentives[17] and is directly influenced by the institutional and regulatory frameworks.[18]

Deciding whether to focus on certain technological trajectories, or diversifying investments to cover myriad emerging technological options, is also a contentious policy-making discussion. Despite multiple perceptions on the topic, there seems to be broad recognition that: a) priorities and needs are continually evolving and, consequently, instruments need to be constantly revised and adapted; b) cooperation and coordination between research centres and industrial activities is particularly critical; and c) national and international cooperation can minimise the risks associated with emerging technologies while creating synergies.[19]

In Brazil the coordination of efforts appears to be a particularly challenging goal. One factor is the diversity of regulations, legislation and jurisdictions coexisting in Brazil.[20] These policies and regulations need to be adapted to local contexts, and simply replicating policy frameworks from other contexts is not likely to work. As a federalist country, Brazil faces the challenge of planning and coordinating municipal, state and national levels, aligning their requirements and leveraging opportunities that vary across different contexts.

Coordinating the actors involved in designing and implementing these policies

As discussed, the current technological developments have a multidisciplinary nature, and therefore multiple sources of expertise need to be brought together in order to tackle the technical challenges involved in deploying these new technologies. Artificial intelligence (AI), for example, is seen as a potentially disruptive technology in its own right. For many firms, however, what is important is the way in which AI can improve their competitiveness, which involves its integration into solutions – including, for example, predictive maintenance and "smart" supply chain management solutions – that can be integrated into their processes. Exploiting the

[17] Public governance incentives fall into four broad categories of policy instrument: a) market, i.e. economic incentives to generate and diffuse innovations; b) regulatory, i.e. defining legal patterns to shape both industrial and consumer behaviour; c) volunteer, i.e. negotiations between governments and/or other organisations; and d) informative, i.e. informing or educating enterprises and the civil society at large. Jordan, A., & Lenschow, A. (2008). *Innovation in environmental policy? Integrating the environment for sustainability*. Edward Elgar.
[18] Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), 1257–1274.
[19] Savaget, P., & Carvalho, F. (2016). *Investigating the Regulatory-Push of Eco-innovations in Brazilian Companies* (pp. 27–37). Springer, Cham.
[20] Ibid.

potential of AI, therefore, requires different types of not only software and ICT expertise but also mechanical and electronics engineering, and the mix of expertise required will vary from sector to sector.

Furthermore, the process of enhancing technological capabilities involves trial-and-error, feedback loops, and cooperation between design, engineering, marketing and other functions, as well as between a wide range of stakeholders, such as suppliers and customers.[21] To promote socio-economic development, it is critical to shed light on how best to coordinate system change, including knowledge and technologies, actors and networks, and institutions.[22]

Ensuring the coordination and alignment of efforts among actors is challenging because of the uncertainty associated with new technology development, the potential cross-cutting impact of some technologies, and the multiplicity of actors and funding sources involved in promoting innovation. Relevant actors include universities and public and private research centres, funded by multiple sources, investing in similar areas without an understanding of how individual efforts might be complementary.

Government activity includes not only creating an ecosystem that enables innovative endeavours to flourish, but also taking entrepreneurial roles by directly nurturing promising technological niches (e.g. with accelerators, incubators or technological parks), or by employing models of venture capital or equity. Such is the case with BNDES Participações.[23]

Governments can take an active role in catalysing or proactively promoting collaboration…

Since a diverse set of stakeholders needs to be articulated, it becomes critical to bring together expertise in different technology domains and research disciplines that reflect the particular interests of each stakeholder, in order to align them towards shared goals. The diffusion and deployment of new technologies require the coordination of agencies and initiatives to achieve critical mass, to ensure rapid uptake in industry and to avoid duplication of efforts.

Furthermore, companies struggle to adopt technologies even when they are available in the market. Thus, various types of support are required, not only to promote R&D but also to increase the absorptive capacity of domestic industries, including the provision of funding support for SMEs.[24,25]

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[21] Ibid.

[22] Malerba, F. (2004). *Sectoral systems of innovation: concepts, issues and analyses of six major sectors in Europe*. Cambridge University Press.

[23] Mazzucato, M. (2013). *The entrepreneurial state: debunking public vs. private sector myths*. Anthem Press.

[24] OECD (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.

[25] The case studies, presented later in this document, will provide examples of how to address these challenges.

2.2 Scale-up and "manufacturability" of emerging technologies

Key points of this section

- New disruptive technologies are expected to drive many changes in the industrial landscape, reshaping global value chains and information networks.
- The operations of companies might become more decentralised, automated and interdependent.
- It is increasingly important not only to create new value, but also to focus on capturing, delivering and exchanging value from the generation and absorption of innovations.
- Governments around the world are emphasising the scale-up of new technologies to ensure that innovations reach the market and achieve economic benefit for the country.
- There are major implications for funding the mechanisms and supportive infrastructures needed for emerging technologies to flourish; and, consequently, for how policy-makers design, implement and integrate their policies.
- Governments can make innovation-driven growth more socially inclusive by sharing both the risks and rewards of technological development and uptake with innovating companies.

Overview

The technological developments associated with the so-called fourth industrial revolution[26] are likely to reshape global value chains and information networks. Technological convergence of sensors, data analytics and cloud computing, to cite a few, can create sophisticated changes to the operations of companies, which might become more decentralised, automated and interdependent. These trends have important implications for the competitive advantage of national industries in the global market, as well as for the types of policy needed to drive innovation and national competitiveness.[27]

As the challenges involved in driving new technological development become more uncertain and gain greater scale and complexity, the following aspects become critical for policy-makers and industrialists alike:

- **Scale up novel technologies**, to translate innovations into the market;
- **Convergence of digital technologies**, which refers to the combination and integration of technologies with the potential to enable a range of new applications and new markets;
- **Funding mechanisms and supportive infrastructures** that are critical to foster the scale-up and manufacturability of nascent technologies.

Scale-up of novel technologies

Scale-up has to do with the translation of an innovation into the market…

A concise definition of scale-up is provided by the US report *Accelerating US Advanced Manufacturing:*[28] “Scale-up can be defined as the translation of an innovation into a market. There are significant technical and market risks faced by new manufacturing technologies during scale-up. The path to successful commercialization requires that technologies function well at large scale and that markets develop to accept products produced at scale. It is a time when supply chains must be developed, demand created and capital deployed.”

Manufacturability challenges are associated with the scale-up of science-based technologies that may require new R&D-based solutions, production technologies and infrastructure…

The implications of scaling up emerging technologies include:[29]

- *Operational and organisational scale-up of manufacturing businesses*, in which emerging and potentially pervasive technologies move from the prototyping and experimentation taking place within

[26] Schwab, K. 2016. The fourth industrial revolution. Davos: World Economic Forum.
[27] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[28] PCAST (2014). *Accelerating U.S. Advanced Manufacturing*. President’s Council of Advisors on Science & Technology. Executive Office of the President.
[29] OECD (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.

niches towards wide market diffusion, influencing the technical and operational capabilities and structures of companies of different sizes and sectors. Particular scale-up challenges include "finding employees to hire who have the skills they need; building their leadership capability; accessing customers in other markets/home market; accessing the right combination of finance; and navigating infrastructure".[30]

- *Production scale-up of a technology-based product*, in which emerging technologies can be nurtured to incorporate new functionalities, to improve its applicability to realistic factory environments and improve cost-effectiveness at greater production volumes. Here, there is a potentially significant role to be played by pilot line programmes, demonstration and testing infrastructure, to cite a few.
- *Product value chains or markets scale-up*, in which the development and redistribution of manufacturing-related capabilities support new products, business models and markets throughout expanded value chains. This might require cooperation across different stakeholders within the value chain, from raw materials production to end-users, and through comprehensive linkage programmes, institutional arrangements and diffusion mechanisms – such as intermediate R&D institutes and technological roadmaps.

Scale-up has a multidimensional nature, involving technologies, products, business models and whole value chains…

A review of the main manufacturing R&D priorities and programmes at international level suggests that the scale-up of novel technologies may involve several dimensions, to include:

- *Technology development scale-up*: this has to do with the transformation of a laboratory prototype into an integrated packaged product with the potential of full-scale production, due to the technical challenges and risks faced in these processes.
- *Process/production scale-up:* this dimension has to do with the necessity to demonstrate functionality, applicability and cost-effectiveness at greater production volumes of novel technologies.
- *Business scale-up:* this has to do with the necessity of firms to expand their technical and operational capabilities, and organisational structures, once the new technology application evolves from a prototype to a niche market, to a larger market.
- *Value chain scale-up:* this is related to developing and redistributing manufacturing-related capabilities to support new products, business models and markets that lead to the creation of new value chains.[31]

Governments have proven to be critical in supporting the scale-up of innovative technologies, especially when crossing the so-called "Valley of Death", that is, the stage of technological development in which the risks are very high and the markets nascent or even non-existent. Governments can assist scaling up, also ensuring that the benefits arising from their investments return to public funds to promote fairer distribution of the benefits of innovation among society at large. Governments have, however, been criticised for not reaping some of the corporate returns from these innovative endeavours, despite sharing the risks of technological

[30] Coutu S. (2014). The Scale-up Report on UK Economic Growth. Information Economy Council.
[31] OECD (2017).

development with innovative companies. It is thus critical to share the risks, but also the rewards, with companies, allowing "smarter" growth to become more "inclusive" too.[32]

Convergence of technologies

It is at the convergence of key enabling technologies – such as ICTs (cyber-physical systems, big data, the IoT), advanced materials, industrial biotechnology and nanotechnology – that the manufacturing revolution is likely to occur.[33] The complexity and immaturity of emerging technologies, nonetheless, pose challenges to convergence, especially in emerging economies, such as Brazil.

Convergence occurs at multiple dimensions:[34] a) vertically, by integrating tools, unit processes and production lines (often discussed as "smart factories"); b) horizontally, when integrating inter-company value chains and networks (aka "smart supply chains"); c) and along product life cycles, by integrating digital end-to-end activities across the entire value chain of products or services.

At device level, convergence has historically proven its potential to lead to novel combinations to deliver new functionalities and applications.[35] Many new high-value products depend on the combination of a wide range of technologies. In fact, some of the most potentially disruptive ones arose from convergence, such as quantum technologies (combining digital IT and advanced materials) and synthetic biology (digital IT and biosciences). Offering new functionalities can also challenge the standard operations of companies, and consequently their ability to generate high-production output.

Beyond device level, the convergence of pervasive technological developments offers the potential to best integrate and connect industrial systems, suppliers and customers, across sectors and geographical regions. This enables faster development and deployment of new products, more efficient logistics and more customised business offerings.

Convergence opens up scope for innovation and underpins diverse ways of capturing new value…

Among the potential responses is fostering hybrid manufacturing systems and interdisciplinary R&D endeavours, making up combinations of different technologies and research areas. These are more likely to nurture convergence solutions in high-value niches – capable of shortening value chains and reducing organisational efforts – and promote the adaption of key enabling technologies to

[32] Lazonick, W., & Mazzucato, M. (2013). The risk–reward nexus in the innovation–inequality relationship: Who takes the risks? Who gets the rewards? *Industrial and Corporate Change*, 22(4), 1093–1128.
[33] OECD (2015). Enabling the Next Production Revolution: Issues Paper. Directorate for Science, Technology and Innovation. Organisation for Economic Co-operation and Development.
[34] O'Sullivan E., & López-Gómez C. (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in OECD (2017), *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.
[35] Roco, M. C. et al. (eds.) (2013). "Convergence of knowledge, technology and society: Beyond convergence of nano-bio-info-cognitive technologies", a study by the World Technology Evaluation Center.

different geographically and sectoral contexts.[36]

Manufacturability

Manufacturability relates to the ability to produce at industrial scale. The infrastructures required to ensure manufacturability are critical for allowing companies to fulfil their innovative potential. However, such infrastructures often involve relatively high capital costs.

Manufacturing infrastructure requires combinations of tools and facilities for convergence and scale-up. This includes, for example, demonstration facilities for companies, such as pilot lines and test beds, bringing together a mix of enabling technologies and technicians to operate them. This can contribute significantly to enhancing the likelihood of companies absorbing and adapting key enabling technologies.[37] Investments in industrial parks, corporate-like technical centres and collaborative arrangements are also likely to foster entrepreneurial activity among new entrants, transforming knowledge and technology from the laboratory of public and private research centres into marketable solutions.[38]

In Brazil, for example, responsibilities for infrastructure are diffused among a vast array of governmental agencies; hence, well-defined goals and alignment of a diverse set of public efforts seem imperative in order to best promote infrastructure investments that, in turn, create an ecosystem for companies to flourish.[39]

Development banks can invest public money on increasing productivity and innovativeness of companies, as well as on building the infrastructure required for their operation. These are local (e.g. Banco de Desenvolvimento de Minas Gerais – BDMG), national (e.g. Banco Brasileiro de Desenvolvimento Econômico e Social – BNDES) or intergovernmental (e.g. Interamerican Development Bank – IADB) financial organisations concerned primarily with the provision of long-term capital to productive sectors and for infrastructure, often accompanied by technical and managerial assistance.[40]

These banks may also decide upon equity participation, usually as minority partners, when projects are seized as strategic, such as for the development of nascent technologies.[41] The priorities of development banks, however, need to be coherent and well coordinated with other national policies, especially ones for science, technology, innovation, and educational and industrial development.[42]

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[36] Idem.
[37] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[38] OECD (2011). Workforce skills and innovation: an overview of major themes in the literature.
[39] de Brito Cruz, C., & L. de Mello (2006). "Boosting Innovation Performance in Brazil", *OECD Economics Department Working Papers*, No. 532, OECD Publishing, Paris.
[40] UNCTAD (2014). Transforming Economies: making industrial policy work for growth, jobs and development.
[41] IPEA (2008). Políticas de incentivo a inovação tecnológica.
[42] Lazzarini, S., Musacchio, A., Bandeira-de-Mello, R., & Marcon, R (2011). What do Development Banks do? Evidence from Brazil, 2002–2009. *Harvard Business School Working Paper*, 12–47.

2.3 SME capability-building

Key points of this section

- SMEs tend to have low absorptive capacity and thus are often unable to adopt technologies that are already available in the market. The smaller the company, the harder it finds it to engage in innovation.
- It is critical to promote the absorptive capacity of SMEs to enhance their ability to effectively absorb and exploit new knowledge and technologies.
- A number of policy support mechanisms can help SMEs to leverage the potential of emerging technologies.
- There is scope for governments to target SMEs with high growth potential, boosting their capacity to absorb existing technologies and develop proprietary ones.

Overview

It is expected that both established companies and start-ups will be affected by new technologies. These technologies are expected to transform how businesses organise their productive systems, interact with stakeholders, coordinate and employ resources and commercialise output.

In this context, there is an intense debate internationally on the role of government in supporting the efforts of firms of different sizes and sectors of the economy to employ these emerging technologies to exploit existing and future business opportunities.

According to the Brazilian Institute of Geography and Statistics (IBGE),[43] SMEs contribute to 27 per cent of the country's GDP and 52 per cent of formal jobs.[44] However, as a result of weak "absorptive capacity", many firms, particularly SMEs, fail to exploit the opportunities offered by technologies available in the market to update products and processes.

There is scope for the government to nurture SMEs' abilities to develop and absorb technologies, hence transforming the industrial landscape.[45] The following aspects seem to be critical of these ambitions:

- **Absorptive capacity**, which is the ability to recognise, acquire, assimilate, transform and exploit knowledge and technologies.[46]
- **Contextual enablers,** the contextual characteristics shaping the performance of existing businesses and the emergence of new entrants.

Governments can systematically stimulate the absorptive capacity of SMEs, while simultaneously addressing contextual characteristics that are holding their performance back. By combining these priorities, governments can increase the likelihood of SMEs being better positioned to leverage industrial opportunities to drive technological change.

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[43] IBGE (2014). Demografia das empresas.
[44] Sebrae (2014). Micro e pequenas empresas geram 27% do PIB do Brasil .
[45] Suzigan, Wilson, & Furtado, João. (2010). Instituições e políticas industriais e tecnológicas: reflexões a partir da experiência brasileira. *Estudos Econômicos* (São Paulo), 40(1), 7–41.
[46] Absorptive capacity is defined by Cohen and Levinthal (1990) as "the ability to recognize the value of new information, assimilate it, and apply it to commercial ends". This capacity is largely a function of the firm's level of prior related knowledge, and it is considered critical to its innovative capabilities. Cohen and Levinthal (1990), "Absorptive capacity: A new perspective on learning and innovation", *Administrative Science Quarterly*, Volume 35, Issue 1, pp. 128–152.

Absorptive capacity

Companies will be increasingly pressured to open up scope to learn beyond their current knowledge basis, by promoting the assimilation and application of new technologies for commercial purposes.[47]

The ability to recognise, acquire, assimilate, transform and exploit knowledge and technologies underpins the wide-scale diffusion of emerging technologies …

Whereas the concept of absorptive capacity is mostly used to refer to organisations, a nation's absorptive capacity is linked to the ability of its agents to acquire and internalise knowledge. The national absorptive capacity is, nonetheless, more than the sum of the capacities of single agents, since myriad institutional features play an important role in the trajectory of technological accumulation.[48]

Larger firms count, having more access to supportive public and private infrastructures and funding mechanisms to enhance their absorptive capacity. On the other hand, SMEs and new entrants will struggle if they do not have the proper incentives in place to incubate their development. They also tend to receive lower priority in innovation policies. Even when targeting SMEs, public efforts tend to target exclusively conventional early adopters, such as high-technology start-ups.

Some of the key enabling technologies, such as ICTs, have lower barriers to entry than other science-intensive and rather expensive technological clusters, such as nanotechnology or biotechnology. The former is highly pervasive and can be incentivised across a wide spectrum of SMEs because of the ease of diffusing these technologies. The latter, on the other hand, requires higher public and private R&D efforts, a longer timeframe, and investments, but is likely to be an imperative for competitive advantage of a subset of knowledge-intensive SMEs.[49]

To cope with fast-paced changing environments and with the specific needs of SMEs, it is important to become increasingly agile and adaptive, constantly assessing technological change and responding quickly. Governments may have to fund the technological adoption of emerging and pervasive technologies that are already available in the market for SMEs; otherwise, they risk market displacement in their respective sectors.

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[47] Zahra, S. A., & George, G. (2002). Absorptive Capacity: A Review, Reconceptualization and Extension. *Academy of Management Review*.
[48] Cohen, W. M., & Levinthal, D. a. (1990). A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), 128–152.
[49] OECD (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.

Contextual enablers

Contextual enablers are the institutional and macro-environmental features that businesses do not have control of, but which shape their performance, as well as the emergence of new entrants.

Governments can boost the ability of companies to generate and deploy technologies by incentivising contextual enablers, and addressing the contextual characteristics holding companies back…

Critics argue that it is critical to create an ecosystem that is capable of nurturing the development of existing SMEs, as well as new entrants, protecting and building up momentum for promising knowledge-intensive SMEs.[50] Governments can incentivise new forms of business organisation and collaboration – such as incubators, accelerators, technological parks and spin-offs from universities or larger companies – and remove disincentives for firm exit and barriers to growth.

Providing shared facilities to local start-ups and small manufacturers can also substantially help SMEs to scale up new technologies, to accelerate technology transfer to the marketplace and to facilitate the adoption of new skills.[51] Equally important to upgrading productive systems is establishing industrial standards and certifications to provide a dominant design that can be built upon by multiple agents.[52]

Specific to the case of knowledge-intensive SMEs, with projects of generating proprietary technologies, governments can boost their dynamism, employing mechanisms such as subsidies and other trade incentives. Public agencies can promote nascent technologies through procurement or by establishing collaborative networks and institutional mechanisms to facilitate public–private partnerships and technology transfers for promising SMEs.[53]

In developing regions, SMEs often focus on meeting the existing, yet largely ignored, demands of low-end consumers, without great ambitions for innovation. In fact, the distribution of the socio-economic impact of SMEs can be best represented through a spectrum ranging from high-impact firms to poor performing ones, in which most are skewed towards the latter.[54] The so-called gazelles – that is, companies with the potential to grow rapidly[55] – are rare, but possess a high transformative effect if their potential is met. It is thus critical for governments to target and support them, providing the conditions that they need to flourish.

The development of key enabling technologies may also require vast investments in basic and

[50] Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, 41(6), 1025–1036.
[51] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[52] Abernathy, W., & Utterback, J. (1978). Patterns of Industrial Innovation. *Technology Review*, 41–47.
[53] O'Sullivan E., & López-Gómez C. (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in OECD (2017), *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.
[54]Nightingale, P., & Coad, A. (2014). Muppets and gazelles: political and methodological biases in entrepreneurship research. *Industrial and Corporate Change*, 23(1), 113–143
[55]Birch, D. L., & Medoff, J. (1994). "Gazelles", in L. C. Solmon & A. R. Levenson (Eds.), *Labor markets, employment policy and job creation* (pp. 159–167). Boulder, CO: Westview.

applied R&D, and SMEs are unlikely to fund these endeavours with their own resources. Some argue that there is scope for governments to provide R&D grants; promote cross-fertilisation between SMEs, public R&D centres and universities; articulate collaborative arrangements across companies of different sizes; and encourage pre-commercial R&D activities, such as feasibility studies, market research or prototyping.[56]

Access to finance for SMEs is also critical to supporting the uptake of emerging technologies…

Young ventures keen on developing new, yet uncertain, technologies would pay, on average, much higher interest rates than larger, established firms. As a result of their constrained cash flows, and the short life cycles of emerging technologies, smaller firms could benefit most from accessing credit to undertake innovation ventures. Policies could extend the scope of industrial or innovation policies by providing credit for SMEs at lower rates for the adoption and development of new technologies. In addition to doing this through public banks or specialised SME lending, governments can also stimulate the participation of commercial banks and venture capital firms in funding innovative projects of SMEs with tax incentives.[57]

[56] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[57] IPEA (2008). Políticas de incentivo a inovação tecnológica.

2.4 R&D collaborative networks

Key points of this section

- A significant proportion of firms do not engage in R&D activities.
- Not all firms have the capabilities to fully engage and benefit from the advantages of the national innovation system.
- R&D linkages, partnerships and interdisciplinarity can help pool the strengths of multiple agents in order to address emerging challenges.
- R&D collaborative networks can help SMEs identify research projects that are relevant to their businesses, in a synergetic environment with other SMEs, as well as larger firms.
- Investments in R&D infrastructure are also critical, and they have to take into consideration the interests and potential gains of industries, of scientific communities and of society at large.

Overview

The generation and deployment of different kinds of innovation, including new products, services or processes, require systematic incentives for public and private R&D. Designing these networks is one of the policy tasks that taps into the latent potential of emerging technologies to drive industrial competitiveness and catch up to the technological frontier.[58] For policy-makers, these challenges imply not only making decisions about what combination of technological domains to prioritise for R&D investments, but also designing institutions and initiatives in a joint effort with representatives of industrial systems and the relevant stakeholders to translate research into innovation.[59]

The following areas are particularly critical:

- **Networked strategies**, articulating a wide range of organisations to pursue common objectives.
- **R&D infrastructure and partnerships**, including facilities, resources and related services, as well as the partnerships needed to catalyse the generation and deployment of new products or services.

The scale and complexity of challenges involved in advancing new technologies go beyond the capabilities of individual actors. Thus, they require linkages and partnerships of a diverse set of organisations through networked R&D strategies. These strategies require the active involvement of industries of different sizes and sectors, in addition to a wide range of stakeholders that influence industrial performance, such as universities, governmental agencies, suppliers and customers, to cite a few. These challenges also indicate the need to invest in R&D infrastructure and partnerships, without which countries cannot meet their latent potential for generating and absorbing emerging technologies.

Networked strategies

Policy-makers face the challenge of leveraging diverse R&D priorities among organisations….

Since the growth of global value chains and information networks, collaborative relationships have increased significantly within and across borders. This involves the active engagement of the so-called triple helix – governmental, industrial and academic organisations.[60] However, R&D priorities vary among organisations and, therefore, policy-makers may need to leverage their diverse sets of strengths and articulate them, whenever possible, to pursue common objectives.

[58] Mazzoleni, R., Nelson, R (2007). Public research institutions and economic catch-up. *Research Policy,* 36, 1512–1528.
[59] O'Sullivan E., & López-Gómez C. (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in OECD (2017), *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.
[60] Leydesdorff, L. (2000). The triple helix: an evolutionary model of innovations. *Research Policy*, 29(2), 243–255.

Policy options include international collaboration, public–private partnerships, industrial grants and infrastructure investments, to cite just a few mechanisms capable of fostering connections. Such mechanisms can bridge organisations with very different characteristics – in terms of organisational structure, sector and geography – to identify synergies, combining their tangible and intangible resources for mutual benefit.

In their efforts to identify synergies, governments need to prevent networks from being captured by vested interests, especially when dealing with priority areas of well-funded lobbying groups. Responses to anticipate these risks include assessing multiple expectations, goals and interests of the involved agents, establishing the governance principles aligning them and formalising the distribution of benefits and responsibilities through contracts.

Furthermore, when designing collaborative networks, governments should be particularly aware of ownership of intellectual property rights. Governments are critical partners to innovate, especially when these innovative endeavours involve high risks or emulate a new market. Sharing the risks and rewards among the public and private actors thus involves coordinating and combining their pool of resources to increase the likelihood of successful technological development and implementation, as well as rewarding agents for their involvement.

Integrated R&D efforts might be needed across multiple productive areas and systems…

Many of the most important R&D challenges are likely to need to draw on traditionally separate technological domains, such as advanced materials, production tools and operations management. For example, the aim of aerospace firms such as Embraer to make next-generation aircraft lighter will require the collaboration of experts on, for example, aerodynamic models, additive machining, composite materials, systems integration, batteries and fuel cells, among many others.[61]

The challenges posed by the productive revolution also underlie the need to integrate different sets of skills, both within and beyond the borders of single R&D centres. This includes manufacturing engineers, industrial researchers, designers and shop-floor technicians.[62]

The characteristics of emerging technologies also pose new contingencies to clusters of geographically concentrated companies and research organisations versed in specific R&D disciplines. These clusters are not necessarily new, but they will be highly influenced by globalised value chains and emerging technologies. Since these technologies will become increasingly more multidisciplinary and pervasive, organised and rather specialised, R&D clusters will also engage with partners working on different technologies and skill sets from different geographical locations, while simultaneously enhancing knowledge spill-over and

[61] AGP, 2013; NASA, 2016.
[62] OECD (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.

development of complementary capabilities within the region.[63]

SMEs struggle to engage in R&D and sometimes they do not have innovation strategies in place…

It is important to pay special attention to SMEs, since they are likely to struggle to engage in R&D and other innovation activities. Some of them do not even have formalised innovation strategies. Since they are more resource-scarce than large companies, they are not able to invest many of their own resources into developing or even absorbing emerging technologies.

However, if they are part of networked strategies for R&D, they can tap into the tangible and intangible resources of multiple partners, while reducing the burden and financial uncertainty of participating in innovation projects.[64]

R&D infrastructure and partnerships

R&D infrastructures are conformed by facilities, resources and related services that can catalyse innovation…

R&D infrastructures can range from generation to the deployment of new products of services. They shape efforts that are led individually or collectively by different centres, including universities, companies and public centres.[65]

Decisions about planning, funding or implementing infrastructure often depend on the priorities of the investing bodies. Publicly funded infrastructure needs to take into consideration the interests and potential gains of industries, scientific communities and society at large. R&D infrastructure is often very costly and involves a broad and multidisciplinary range of expertise. Most private R&D investments are funded by the company's own resources.[66] Consequently, barriers to entry depend on the area of knowledge (for example, ICT has relatively low barriers to entry when compared to advanced materials).

Besides the ability of R&D centres to create knowledge and technologies, it becomes increasingly clear that translating knowledge and technology from the laboratory into commercialised solutions is also crucial. This is particularly challenging in the case of basic research, which is hardly translated into potentially marketable solutions. As manufacturing challenges gain greater scale, uncertainty and levels of complexity, the need for comprehensive sets of infrastructure becomes even more critical for convergence and scale-up.

In Brazil, government-funded R&D exceeds privately funded research,[67] a situation that is

[63] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[64] Ibid.
[65] European Union (2011). Strategy Report on Research Infrastructures: Roadmap 2010.
[66] IPEA (2008). Políticas de incentivo a inovação tecnológica.
[67] In 2014 private R&D represented 0.55% of the Brazilian GDP and public research represented 0.61%. While its private R&D investments lag behind many developed regions (such as South Korea, which invests 2.68% of its GDP), its public R&D investments/GDP is approximate to the OECD average of 0.69%. World Bank (2017). The World Bank Data.

different to that found in many high-income countries. As such, there might be scope for the government to strengthen private R&D, by financing it directly through grants, providing incentivised credit or tax benefits .[68]

Public R&D generally happens within organisations endowed by governments, including, for example, labs for basic research, research vessels and institutes for applied research.[69] For an emerging country, such as Brazil, public research institutes are central players supporting "catching-up" to the technological frontier.[70]

These centres can play a variety of roles, including knowledge generation and diffusion to foster economic development, qualification and training of the workforce in industries, and tackling context-specific environmental and social vulnerabilities. A few examples in Brazil include IMPA, Fiocruz, Instituto Butantã, Embrapa, and research units from the Ministry of Science, Technology, Innovation and Communications.[71] Their different roles can be integrated and their priorities aligned with the next production revolution strategies.

Policies to enhance knowledge transfer can also include deploying intermediaries or creating platforms for exchanging knowledge, technologies and good practices, as well as targeted, collaborative models keener on suiting industrial needs by opening up scope for the combination of a diverse pool of assets from different organisations.[72]

Since technologies will increasingly converge and contexts will evolve in rather unpredictable ways, effective public and private R&D centres need to have the flexibility to relocate resources and efforts and learn by trial-and-error. In this way, they can improve their likelihood of building capabilities and cooperate with external agents to develop new marketable products or services. Equally important is shaping the commercialisation of R&D output by fostering entrepreneurial ventures spinning-off from pre-commercial R&D networks, by easing bureaucracies and legal constraints. Interdisciplinarity can also be fostered throughout collaborative R&D efforts, ensuring the integration of multiple research areas and skills, and by organising networks around grand challenges that cannot be tackled alone by a single discipline.[73]

[68] de Brito Cruz, C., & L. de Mello (2006). "Boosting Innovation Performance in Brazil", *OECD Economics Department Working Papers*, No. 532, OECD Publishing, Paris.
[69] Cohen, W. M., Nelson, R. R., & Walsh, J. P (2002). Links and impacts: the influence of public research on industrial R&D. *Management Science* 48 (1), 1–23.
[70] de Brito Cruz, C., & L. de Mello (2006). "Boosting Innovation Performance in Brazil", *OECD Economics Department Working Papers*, No. 532, OECD Publishing, Paris.
[71] MCTIC (2018). Website.
[72] Mazzoleni, R., & Nelson, R (2007). Public research institutions and economic catch-up. *Research Policy*, 36, 1512–1528.
[73] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.

2.5 Skills development in disruptive technologies

Key points of this section

- The effective adoption of new technologies requires firms to acquire new skills.
- Skill sets will increasingly incorporate interdisciplinary knowledge, requiring more interaction among agents and lifelong upgrading of abilities.
- The skills needed are not restricted to traditional scientific and engineering occupations, but also include technicians, production workers, tradespersons, marketing and financial management.
- The uncertainty of the overall impact of digital transformation on employment is debated, as well as the potential impact on working conditions.
- Governments can attempt to steer changes by anticipating transformations in labour markets.

Overview

The deployment of key enabling technologies can lead to significant benefits for businesses, economies and society as a whole, by enhancing productivity and economic growth. However, in order to tap into the potential of these emerging trends, countries need to be capable of anticipating the development of skills needed for technological deployment, since job requirements of the future can change abruptly. It also seems critical to steer changes in labour markets, since emerging technologies can lead to the displacement of some job categories, while concomitantly creating opportunities in novel professional areas.[74] In this context, the following aspect is particularly important.

Brazil has proven that it can develop proprietary technologies in several sectors, such as aviation and electronics. However, technological development is still derived mostly from the absorption and deployment of technologies from elsewhere.[75] The country has plenty of scope to promote socio-economic progress by actively learning from the deployment of external technologies, and then progressively moving towards generating more radical innovations.[76]

Development of new skills

There is an ongoing debate about the potential impact on jobs arising from new technologies, and estimates about job creation and destruction in traditional businesses and industries may depend on the methodology used and the countries under analysis.[77]

New technologies will have an impact on the labour market by both displacing and creating jobs…

It is likely that highly automated jobs currently undertaken by humans will be displaced by new technologies that, at the same time, will create new jobs that will require new skills. For example, 3D printing of complex objects could eliminate jobs, respectively, for workers in assembly and inventory management, but could also give rise to new occupations, such as computer-aided designers.[78]

Although the pace is uncertain, the importance of nurturing skills and training systems in a magnitude of speed that matches the technological diffusion becomes clear…

Unlike high-income countries, emerging economies, such as Brazil, still face the challenge of ensuring good generic skills across the population – such as literacy, numeracy and problem-solving.[79]

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[74] McKinsey (2017). Jobs lost, jobs gained: workforce transitions in a time of automation.
[75] Suzigan, Wilson, & Furtado, João. (2010). Instituições e políticas industriais e tecnológicas: reflexões a partir da experiência brasileira. *Estudos Econômicos* (São Paulo), 40(1), 7–41.
[76] Fagerberg, J. (1994). Technology and international differences in growth rates. *Journal of Economic Literature*, 32(3), 1147–1175.
[77] CEPS (2017). Impact of digitalisation and the on-demand economy on labour markets and the consequences for employment and industrial relations. European Economic and Social Committee.
[78] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[79] OECD (2015). PISA 2015 Key findings for Brazil, available at: https://www.oecd.org/pisa/pisa-2015-brazil.htm.

However, like any other country affected by digital change, Brazil will also increasingly rely on skilled labour, such as PhDs working in industry and research centres.

The need for new multidisciplinary and digital skills (i.e. data analytics, engineering skills) is expected to increase, and the gap between demand and availability of workers with digital skills is also expected to grow. Focusing only on the ICT sector, for example, the European Commission estimates that a rapidly growing demand for workers in the sector will lead to more than 800,000 unfilled vacancies by 2020.[80]

The capacity to benefit from emerging technologies also depends on the absorptive capacity of the workforce, that is, the ability to acquire and deploy knowledge, as well as new or improved products, services, processes or business models.

Specialist skills in new technologies are required at all levels of the company: from shop-floor operators and technicians, to production engineers, managers and company directors…

Absorptive capacity involves skills that are not restricted to traditional scientific and engineering occupations, such as technicians, production workers, tradespersons, marketing and financial management, to cite a few.[81] It therefore seems very important to nurture skills in new technologies through vocational training systems or higher-education institutions and initiatives of interest, with training focusing on emerging technologies and the development of “super technicians”.[82]

SMEs might also struggle to deploy new technologies, since the scope of the manufacturing workforce is likely to change considerably in the next decade…

Developing interdisciplinary educational and technical skills might, therefore, become an imperative to meet the changing specificities of future labour. Other forms of enhancing technological adoption by SMEs consist of activities such as awareness-raising, training, mentoring, increasing SME research grants, subsidising (or waiving) service fees or voucher schemes for equipment use.

It is also important to highlight that not only are emerging technologies intrinsically multidisciplinary, but also breakthroughs have the potential to trigger change across the entire value chain. Therefore, the generation, adaptation and absorption of new technologies will increasingly require interdisciplinary knowledge, more interactions among a diverse set of agents and lifelong upgrading of abilities to match new job requirements.[83]

Technological advancements coupled with an ageing workforce could lead to a shortage of skilled workers …

Technology may also help to relieve demographic constraints on production. The Brazilian population is expected to grow by 10 per cent by 2030, but this is mostly led by the growth of older age cohorts – a

[80] European Commission (2016). Digitising European Industry: Reaping the full benefits of a Digital Single Market.
[81] Zahra, S. A., & George, G. (2002). Absorptive Capacity: A Review, Reconceptualization and Extension. *Academy of Management Review*.
[82] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[83] Ibid.

phenomenon that is similar to other emerging and OECD economies.[84]

There is a possibility that an ageing workforce, coupled with changing skills requirements, could potentially lead to a shortage of skilled workers, impacting existing and emerging industrial sectors. This mismatch indicates the pressing importance of policies supporting the qualification of the national workforce, including more sophisticated and multidisciplinary skills.[85]

Not only blue-collar, but also white-collar, jobs are threatened, given the gradual increase in the cognitive capacities of technologies such as ICT through artificial intelligence. They rival human performance in tasks where humans were thought to possess a permanent cognitive advantage over machines. This includes, for example, the combination of sensors, control devices, data analytics, the Internet of things, 3D printing and cloud computing, enabling increasingly intelligent and autonomous systems, which are faster, more precise and more consistent than workers.

The overall impact of emerging technologies may depend on the sector affected and the geographical location of industries…

It seems likely that labour-intensive industries, which predominate in many developing countries, such as food or textiles, could be less susceptible to change in the short term than industries with higher aggregated value, such as electrical and electronics.[86] Employment projections should thus take into account the quantitative balance between jobs lost and gained; the characteristics of the jobs lost and those gained; the duration and efficiency of the labour market; and the skills, institutions, micro- and macroeconomic aspects and demographic dynamics shaping the robustness and resilience of the workforce.[87]

Important policy responses include, for example, mobility across public and private sectors that can be encouraged if research funds and human resource policies reward mobility as part of career progression. Countries can also address their increasing demand for labour by welcoming talented foreigners. On the other hand, countries can also face the risk of a “brain drain”. Emigrants can be stimulated to return, bringing back competencies learnt elsewhere.

[84] IPEA (2012). Tendências demográficas mostradas pela PNAD 2011.
[85] WEF (2016). Digital Transformation of industries: societal implications.
[86] UNIDO (2017). Emerging Trends in Global Advanced Manufacturing.
[87] McKinsey (2017). Jobs lost, jobs gained: workforce transitions in a time of automation.

2.6 Case studies overview matrix

Governmental efforts to address the challenges associated with the five opportunity areas will be described in the next section by outlining the scope, objectives and mechanisms of the implementation of selected international case studies.

In order to facilitate the comparison across international programmes, the information collected for each case study is summarised using the matrix below:

Case study overview matrix (example)

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			●
	Coordination failures	●		
	Existence of public good		●	
WHAT Policy goal	Technology development			●
	Industrial competitiveness		●	
	Societal challenges/needs			●
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)		●	
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)	●		
WHO Key delivery stakeholders	National			●
	Regional		●	
	Municipal/local		●	

International approaches will be benchmarked by analysing the *why*, *what, how* and *who* of selected programmes, mechanisms and initiatives, as described below.

The first part of the matrix contains the *why,* namely, the policy rationale/justification for establishment and funding. In this respect, three typologies of *system failure* are reported together with a *market failure* (i.e. the existence of public good).

System failures provide a set of justifications for public support in innovation derived from the innovation systems approach, as opposed to market failures, as defined in the neoclassical approach. The idea of market failures has developed within the neoclassical economics tradition, and is an acknowledgement that there are circumstances in which markets produce sub-optimal outcomes. On the other hand, the innovation systems approach tends to see innovation as not just economically embedded but also socially constructed. Building on economic theories outside the strand of neoclassical economic thought, the innovation systems approach sees the constant evolution of technology as internal to a complex system, and does not necessarily justify government intervention based on failures of the market, but rather failures of the system.

In this respect, the existence of a public good (like infrastructure and education) is a case of neoclassical market failure where failure to align private and national interests justifies government intervention. With regard to the selected case studies, R&D activities or worker training have a characteristic of public good.

On the other hand, information failures, network failures and coordination failures are examples of system failures, as follows:

- **Information failure:** there is no perfect information at the level of the individual firm, and that available information is not always understood.
- **Network failure**: networks are locked into technological regimes, markets or products by their history and capabilities and find themselves unable to transition into new technologies or businesses.
- **Coordination failure**: government to coordinate the operations of various industries for the purpose of economy-wide productivity growth.[88]

The second part of the matrix has to do with the *what,* where the specific policy goal is highlighted, focusing on elements such as the particular innovation challenge addressed, including technology development (i.e. increasing R&D expenditure, promoting technology adoption, developing supply chains for emerging technologies, etc.), industrial competitiveness (i.e. element of industrial system actors targeted, including MNCs, supply chain, production technology suppliers, etc.), or other societal challenges and needs.

The *how* section in the matrix shows the features of the programme based on the types of support offered/funded across innovation functions:

- **Knowledge generation**
- **Knowledge diffusion**
- **Knowledge absorption**

Finally, the *who* will report the public and private institutions/organisations involved in design and implementation (including government ministries and agencies, SMEs and MNCs, etc.), the types of public–private partnerships involved, and the hierarchies, that is, whether the programmes/mechanisms/initiatives are derived from a central government policy or implemented by a regional government/agency.

Information about evaluation/impact assessments is also presented, where possible. However,

[88] For a review of system and market failures, see Technopolis (2014*). The case for public support in innovation*.

some of the programmes and initiatives reviewed have only emerged in recent years and have not yet been formally evaluated, or the evaluation results are not in the public domain.

The qualitative assessment summarised and presented for each case study (including the why-what-how-who matrix) is based on the literature review, benchmarking and expert judgement.

3

Case studies

The aim of this section is to conduct a review of case studies and best practices of how governments across the world are addressing the challenges arising from disruptive technologies associated with the five opportunity areas discussed in the previous section.

Twelve international programmes were shortlisted from a long list comprising over sixty programmes. The 12 selected international approaches were benchmarked by analysing the *why* (i.e. the policy rationale behind the establishment of programmes), the *what* (i.e. the programmes' target and/or focus), the *how* (i.e. the types of support offered and policy instruments being mobilised) and the who (i.e. the level of involvement of public organisations at central or regional level, and private institutions).

The information gathered in this section will inform the comparative analysis conducted in the next section and focus on policy implications.

The following case studies are described in this section:

Opportunity area	Case study
Agency coordination and formation of a common national vision around new technologies	1. National Nanotechnology Initiative (NNI) – United States 2. Swedish Governmental Agency for Innovation (Vinnova) – Sweden
Scale-up and "manufacturability" of emerging technologies	3. Manufacturing USA institutes – USA 4. Made in China 2025 – innovation centres – China
SME capability-building	5. Hollings Manufacturing Extension Partnership – USA 6. Singapore Institute of Manufacturing Technologies, SIMTech – Singapore 7. Innovation & Capability Voucher (ICV), SPRING – Singapore
R&D collaborative networks	8. Central Innovation Programme for SMEs (ZIM) – Germany 9. German Federation of Industrial Research Association (AiF) – Germany
Skills development in disruptive technologies	10. SkillsFuture Singapore programmes at SIMTech – Singapore 11. NIBRT programmes (Ireland) 12. KOMP-AD – Denmark

Agency coordination and formation of a common national vision around new technologies

3.1 National Nanotechnology Initiative (NNI) – USA
3.2 Swedish Governmental Agency for Innovation (Vinnova) – Sweden

National Nanotechnology Initiative (NNI)

Overview

The National Nanotechnology Initiative (NNI) is a research and development (R&D) strategy involving the nanotechnology-related activities of 20 US departments and independent agencies.

The NNI seeks to bring together the expertise needed to advance the broad and complex field of nanotechnology by creating "a framework for shared goals, priorities, and strategies that helps each participating Federal agency [to] leverage the resources of all participating agencies".[89]

Since the NNI's establishment in 2001, NNI agencies have invested more than USD 25 billion in nanotechnology research, development and commercialisation. The 2018 federal budget provides more than USD 1.2 billion for the NNI.

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures	●		
	Coordination failures			●
	Existence of public good		●	
WHAT Policy goal	Technology development			●
	Industrial competitiveness		●	
	Societal challenges/needs		●	
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)		●	
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)	●		
WHO Key delivery stakeholders	National			●
	Regional	●		
	Municipal/local	●		

[89] NSTC (2016). National Nanotechnology Initiative – Strategic Plan. National Science and Technology Council.

Policy rationale (Why)

The National Nanotechnology Initiative (NNI) is a collaboration of 20 US federal agencies and Cabinet-level departments with shared interests in nanotechnology research, development and commercialisation. The initiative's vision is to enable "*a future in which the ability to understand and control matters at the nanoscale leads to a revolution in technology and industry that benefits society*".[90]

Inter-agency coordination efforts such as the NNI are particularly relevant to addressing information and coordination failures that arise in the context of both complex institutional arrangements and large-scale multidisciplinary technological challenges.

On the institutional aspect, the NNI has been conceived as an effort to ensure that R&D investments across the US government are coordinated more effectively. In particular, the NNI is expected to play an important role in creating consensus among federal agencies on the high-level goals and priorities in the field of nanotechnology, while providing clarity on how individual member activities contribute to such high-level goals. The NNI aims to create a framework for "shared goals, priorities, and strategies" that helps to "leverage the resources of all participating agencies".[91]

On the technological side, there is an explicit recognition that, because nanotechnology is a broad and complex field, multiple types of expertise need to be brought together to accelerate its impact in industry and society. The advancement of nanotechnology depends on developments in areas such as biology, chemistry, materials science and physics. Furthermore, its application ranges from health care and cosmetics to consumer electronics, apparel and automotive.

Policy goals (What)

The NNI's efforts primarily seek to expedite the discovery, development and deployment of nanoscale science, engineering and technology.

In order to achieve this, four goals have been established:[92]

1. Advancing a world-class nanotechnology research and development programme;
2. Fostering the transfer of new technologies into products for commercial and public benefit;
3. Developing and sustaining educational resources, a skilled workforce and a dynamic infrastructure and toolset to advance nanotechnology;
4. Supporting the responsible development of nanotechnology.

These goals reflect the fact that while the NNI is primarily described as an "inter-agency research and development (R&D) effort", the initiative also emphasises the potential role of nanotechnology in supporting the competitiveness of US industries and the country's ability to address societal challenges. The NNI argues that nanotechnology has evolved from an area of fundamental research to an "enabling technology". The initiative, initially concerned with "foundational" or "fundamental" research, has thus expanded to include activities directed at how novel nanotechnology materials and devices can be incorporated into nanotechnology-enabled systems.

[90] NSTC (2016).
[91] NSTC (2016).
[92] NNI (2017). About NNI.

The Department of Energy (DoE), one of the key agencies involved in the NNI, for example, views nanoscience and nanotechnology as having a vital role to play in solving energy and climate-change challenges. This is because nanotechnology has the potential to drive advances in areas such as solar energy collection and conversion, energy storage, alternative fuels and energy efficiency.

Types of intervention supported (How)

The NNI is managed within the framework of the National Science and Technology Council (NSTC), the Cabinet-level council under the Office of Science and Technology Policy at the White House, through which the President coordinates science, space and technology policies across the federal government of the United States.

Funding support for the NNI comes directly from 11 of the participating agencies, rather than from a central NNI budget. The nanotechnology budgets of these agencies are reported in the annual NNI Supplement to the President's Budget. This supplement also highlights accomplishments and future plans. While the NNI does not have a central budget, it informs and influences federal budget and planning processes through its individual participating agencies and through the NSTC.[93]

Since the NNI's establishment in 2001, NNI agencies have invested more than USD 25 billion in nanotechnology research, development and commercialisation. Federal organisations with the largest investments include: National Science Foundation (NSF), National Institutes of Health (NIH), Department of Energy (DoE), Department of Defense (DoD) and the National Institute of Standards and Technology (NIST).[94]

In addition to providing fabrication, characterisation and testing capabilities, the NNI emphasises the need to ensure access to state-of-the-art physical infrastructure. Physical infrastructure is seen as having a primary role, not only in enabling research activities but also in providing a place for researchers, industry and ideas to mix.[95] According to the NNI's 2016 Strategic Plan:[96]

"In many cases, single researchers or institutions find it difficult to justify funding the acquisition of and support for all necessary tools… [U]ser facilities critically enable research and development and accelerate commercialization by co-locating a broad suite of nanotechnology tools, maintaining and replacing these tools to keep them at the leading edge, and providing expert staff to ensure the most productive use of the tools. The facilities also support the development of advanced nanoscale fabrication methods and measurement tools. Finally, shared facilities are a vital resource for training nanotechnology researchers and for creating a community of shared ideas by mixing researchers from different disciplines and sectors."

NNI user facilities include the NSF National Nanotechnology Coordinated Infrastructure (NNCI), DoE Nanoscale Science Research Centers (NSRCs), NIST Center for Nanoscale Science and Technology (CNST) and the National Cancer Institute (NCI) Nanotechnology Characterization Laboratory (NCL).

NNI strategic plans

93 Ibid.
94 NNI (2017). *Funding*.
95 NNI (ND). *About NNI*.
96 NSTC (2016).

An important mechanism to coordinate multiple agency efforts is the development of the NNI Strategic Plan, which NNI agencies are required to develop every three years. This plan represents a consensus among NNI agencies on the high-level goals and priorities of the initiative and on specific objectives to be pursued. **The NNI plans provide the framework under which individual agencies conduct their own mission-specific nanotechnology programmes, coordinate these activities with those of other agencies, and collaborate.**

In addition, the plans highlight opportunities to:

- Leverage complementary activities in existing federal initiatives in health care, information technologies, and advanced materials and manufacturing to broaden the impact of the NNI.
- Engage the general public and inspire the next generation of scientists and engineers, including those from underrepresented groups, through the use of contests and other challenges.
- Build upon the highly regarded NNI collaborations on understanding the potential environmental, health and safety (EHS) implications of nanotechnology, and to use that understanding in developing science-based regulatory policies.

Grand challenges

"Grand challenges" are seen as mechanisms to promote public–private collaborations that accelerate nanotechnology discovery, development and deployment. They seek to set ambitious but achievable goals that "harness science, technology, and innovation to solve important national or global problems and have the potential to capture the public's imagination".

In 2015 the first "Nanotechnology-Inspired Grand Challenge" was announced. It challenges the community to "**Create a new type of computer that can proactively interpret and learn from data, solve unfamiliar problems using what it has learnt, and operate with the energy efficiency of the human brain".**[97]

Examples of success stories

Smart technology for food production

Researchers supported by USDA's National Institute of Food and Agriculture are developing a biosensor that can help farmers calibrate pesticide use. A team of university scientists has designed a graphene-based device to provide real-time, in-the-field measurements of pesticide levels in the soil or water. The graphene substrate developed provides a flexible, low-cost platform and could potentially be adapted for use beyond the agriculture community in the biomedical, environmental and food safety arenas.

Nanotechnologies in manufacturing

National Nanotechnology Initiative member agencies are working with the private sector to build an industry around America's forests by supplying plant-derived nanomaterials for everything from biodegradable electronics to high-strength packaging.

Key delivery stakeholders (Who)

The work of the NSTC is organised under committees that oversee subcommittees and working groups focused on different aspects of science and technology. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee coordinates planning, budgeting, programme implementation and

[97] NNI (2015). A Federal Vision for Future Computing: A Nanotechnology-Inspired Grand Challenge.

review. The National Nanotechnology Coordination Office (NNCO) provides technical and administrative support to the NSET Subcommittee and its working groups in the preparation of multi-agency planning, budget and assessment documents related to the NNI. The NSET Subcommittee is composed of representatives from agencies participating in the NNI.

The NNI provides a central interface for stakeholders and interested members of the general public, including those from academia, industry and regional/state organisations, as well as international counterparts. The NNI community extends beyond the federal government and includes grantees, students, companies, technical and professional societies, foundations and others engaged in nanotechnology research and development. **Twenty** governmental agencies are involved.

Key insights of the programme

A striking aspect of the NNI is the recognition that, in order to take technology forwards, multiple agency efforts need to be coordinated. Naturally, this has been acknowledged by a number of agencies and programmes, but where the NNI goes further is in the establishment of a "framework" to enable this coordination to take place. Such a framework involves practical mechanisms such as the requirement for 20 departments and agencies to work together to produce a joint plan every 3 years, which makes details on expenditure, progress and future plans visible to the highest levels of government and the wider innovation community.

It is important to note that the work of the NNI is, to some extent, only possible thanks to the presence of an important institution such as the Office of Science and Technology Policy (OSTP) at the White House, which is an explicit policy coordinating function on behalf of the President.

An important learning highlighted by the NNI is the critical role that physical facilities can play in enabling collaboration, if the right set of resources are put in place. The NNI's approach has been to ensure that the latest tools, equipment and staff are made available to the community, which provides incentives for multiple stakeholders to collaborate in such spaces of common use.

Swedish Governmental Agency for Innovation (VINNOVA)

Overview

Established in 2001, the Swedish Governmental Agency for Innovation (VINNOVA) aims to strengthen Sweden's innovation capacity and competitiveness, through stimulating collaboration among the different actors of the innovation system. They facilitate the development and implementation of joint research and development projects between companies, universities, colleges, research centres, the public sector and civil society, both in Sweden and internationally. VINNOVA has offices in Stockholm, Brussels and Silicon Valley.[98]

VINNOVA has a large portfolio of instruments and programmes, which are targeted at the following fields: circular and bio-based economy; industry and materials; smart cities; life science; and travel and transport. The focus of VINNOVA initiatives goes from supporting incubators, promoting collaboration, developing strategic, long-term programmes, to funding innovation projects, in both the public and private sectors. Overall, around 45 per cent of the agency's budget goes to universities and 30 per cent to companies. Nearly 60 per cent of company funding goes to SMEs and several of VINNOVA's funding programmes are reserved for SMEs.[99]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			●
	Coordination failures			●
	Existence of public good			●
WHAT Policy goal	Technology development			●
	Industrial competitiveness		●	
	Societal challenges/needs			●
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)			●
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)	●		
WHO Key delivery stakeholders	National			●
	Regional		●	
	Municipal/local		●	

[98] OECD (2013). *OECD Reviews of Innovation Policy: Sweden 2012*, OECD Publishing; VINNOVA, Our activities.
[99] OECD (2013). *OECD Reviews of Innovation Policy: Sweden 2012*, OECD Publishing. VINNOVA (2014), Information VI 2014:10.

Policy rationale (Why)

VINNOVA's core functions address collaboration and network failures. The agency argues that innovation often occurs where knowledge and skills from different areas interact and where organisations learn from one another. For this reason, most of its efforts are concentrated on "stimulating collaborations involving universities and other higher education institutions, research institutes, enterprises and public services working together to develop new solutions".[100]

VINNOVA's efforts also address the gap between private and social costs and benefits (the existence of public good) related to innovation, research and development activities. The agency provides funding in the early stages of innovation processes "where the risks are great and where projects would generally not get off the ground without government aid".[101] Moreover, the agency recognises the need to develop collaboration capabilities among those actors with a key role in the innovation system, but with less expertise in broader synergies, such as small businesses, public research institutions and authorities at local and regional level.[102]

Policy goals (What)

VINNOVA's vision is "for Sweden to become a leading global player in research and innovation, and a country that is attractive for investment and entrepreneurship", while its mission is "to contribute to sustainable growth by improving the conditions for innovation".[103]

Priority fields include: circular and bio-based economy; industry and materials; smart cities; life science; and travel and transport.

Types of intervention supported (How)

VINNOVA activities cover a broad range of functions related to the coordination and formation of a common national vision around new technologies. The agency supports the different levels of knowledge generation, from feasibility to deployment. It provides grants for the development and testing of new technologies, tools and techniques and prototype demonstration. Moreover, VINNOVA facilitates knowledge diffusion through the promotion and funding of business intelligence and networking, both in the country and internationally.

VINNOVA's main instrument for ensuring the coordination and alignment of efforts is the Strategic Innovation programmes. These programmes were launched in 2013 in collaboration with the Swedish Energy Agency and the Swedish Research Council (Formas). The actors involved in each field formulated a common vision and defined needs and strategies for developing an innovation area. The starting point for their agendas was to meet important societal challenges and to create growth and strengthen Sweden's competitiveness in the area. In 2017 there were a total of 17 strategic programmes in areas such as mobility; the Internet of things; metal industries; medical technology and health care; manufacturing automation and digitalisation; the sustainable use of resources; and social housing.[104] Three of these programmes are:

Produktion 2030: an open innovation programme with a 2030 vision – "Sweden's competitive global position in 2030 is based on strategic, long-term initiatives that began in the early 2000s, leading to world-class

[100] Ibid.
[101] VINNOVA. *Our activities*.
[102] VINNOVA (2018). *Årsredovisning 2017.*
[103] Ibid.
[104] VINNOVA (2018). *Årsredovisning 2017.*

research, innovation and education, in collaboration between industry, academia, research institutes, research funding and community members."

Drive Sweden: a programme that gathers leading experts from all sectors of society concerned with mobility and provides funding for projects emerged within this framework.

LIGHTer: a cross-industry lightweight initiative launched in 2013 that intends to create a structure for the development of multi-disciplinary capabilities to create products with low weight.

Challenge-driven innovation programmes also contribute to VINNOVA's coordination efforts. They provide opportunities and incentives for developing public research activities in cooperation with companies, in order to generate solutions to concrete societal challenges.[105]

As part of its coordination activities, VINNOVA contributes to strengthening innovation and collaboration capabilities. The Vinnväxt programme is an example of these activities. It was launched in 2001 with the aim of developing an institutional infrastructure to support innovation systems at regional level.

VINNOVA also disseminates information about research, development and innovation to engage with potential innovation actors.

Coverage and impact

In 2017 VINNOVA invested SEK 3.1 billion (USD 375.6 million) to promote innovation, supporting 3,834 projects.[106]

Success stories

- Company: Exeger. Project: The company produced a new technology for manufacturing solar cells. A pilot factory for mass production was established in Sweden.
- Company: Yubico. Project: Development of a next-generation log-in service. The service is now used by some of the world's largest Internet companies, including Google and Facebook, and is sold in 120 countries.
- A project run by Sweden's Lund University and Skåne Regional Council (Region Skåne) develops IT support for advanced cancer treatment in the home. The results are used in health care.[107]
- Visual Sweden is a Vinnväxt's regional growth and innovation initiative, with its core in the county of Östergötland and with a focus on visualisation, image analysis and simulation. The major areas of application are industrial development and production, medical imaging and community planning. Central actors are Linköping University, Region Östergötland, Linköping and Norrköping municipalities, national governmental institutions and administrations based in the region and around fifty SMEs and large companies.[108]

Key delivery stakeholders (Who)

VINNOVA is a government agency under the Ministry of Industry and the National Contact Authority for the EU Framework Programme for Research and Innovation. VINNOVA works in cooperation with other research financiers and innovation-promoting organisations, including the Swedish Research Council, the Swedish Energy Agency, Almi and the Swedish

[105] VINNOVA (2018). *Årsredovisning 2017.*
[106] VINNOVA (2018). *Årsredovisning 2017.*
[107] VINNOVA (2014). *Information VI 2014:10*.
[108] VINNOVA (2016). *Vinnväxt. A programme renewing and moving Sweden ahead*.

Agency for Economic and Regional Growth.[109] VINNOVA's organisation and partnerships vary from programme to programme. For example, Drive Sweden is funded by the Swedish Energy Agency, the Swedish Research Council Formas and Sweden's innovation agency VINNOVA, while Lindholmen Science Park is the host for the programme. In the case of Vinnväxt, regional and local governments have played a more important role.[110]

Key insights of the programme

VINNOVA is a government agency under the Ministry of Industry and the National Contact Authority for the EU Framework Programme for Research and Innovation. The agency's mission is to strengthen Sweden's innovation capacity and competitiveness, through stimulating collaboration among the different actors of the innovation system, including companies, universities, colleges, research centres, the public sector and civil society. Priority fields of activity include: circular and bio-based economy; industry and materials; smart cities; life science; and travel and transport.

VINNOVA activities cover a broad range of functions related to the coordination and formation of a common national vision around new technologies. Its main instrument to ensure the coordination and alignment of efforts is the Strategic Innovation programmes. The actors involved in each field formulated a common vision and defined needs and strategies to develop an innovation area. The starting point for their agendas was to meet important societal challenges and to create growth and strengthen Sweden's competitiveness. In 2017 there were 17 Strategic Innovation programmes in areas such as mobility; the Internet of things; metal industries; medical technology and health care; manufacturing automation and digitalisation; the sustainable use of resources; and social housing.

[109] VINNOVA. *The role of VINNOVA*. VINNOVA (2014). *Information VI 2014:10*.

[110] VINNOVA (2016). *Vinnväxt. A programme renewing and moving Sweden ahead*.

Scale-up and "manufacturability" of emerging technologies

Manufacturing USA institutes

Overview

Manufacturing USA, or the National Network for Manufacturing Innovation, is a network of linked manufacturing innovation institutes. The aim of these institutes, which are public–private partnerships, is to address the gap between R&D supported by government and product-development work in industry. The specific objectives of this initiative are to:

- Address industry underinvestment in pre-competitive applied R&D;
- De-risk the scale-up of new technologies and materials for USA manufacturers;
- Create the space for industry and academia to collaborate.

A total of 14 innovation institutes have been established since the launch of the initiative in 2014, in areas such as additive manufacturing, integrated digital design and manufacturing, lightweight technology, wide bandgap semiconductors, advanced polymer composites and, most recently, integrated photonics and smart manufacturing, among others. The President's 2017 Budget proposed nearly USD 2 billion for the National Network for Manufacturing Innovation.[111]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			●
	Coordination failures			●
	Existence of public good		●	
WHAT Policy goal	Technology development			●
	Industrial competitiveness			●
	Societal challenges/needs	●		
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)		●	
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)		●	
WHO Key delivery stakeholders	National			●
	Regional			●
	Municipal/local			●

[111] AAAS (2016). Guide to the President's Budget: Research and Development FY 2017. A report by the American Association for the Advancement of Science.

Policy rationale (Why)

The Manufacturing USA initiative is a national strategy designed in response to the United States' decreasing competitiveness in advanced manufacturing. Its focus is on "the challenges faced in the activity space that falls between early stage basic research and technology deployment in manufacturing". The programme aims to bridge the gap between R&D supported by government and the product-development role of industry and to develop a public applied research infrastructure for a variety of technical domains.[112]

The programme intends to address information and network failures by linking SMEs to larger firms, backed by multidisciplinary university applied science and engineering departments. The inter-agency Advanced Manufacturing National Program Office (AMNPO) operates the programme, ensuring correct coordination between the relevant government stakeholders.

Policy goals (What)

The programme's overall goal is to increase the competitiveness of US manufacturing through:

- ***Technology advancement:*** to facilitate the transition of innovative technologies into scalable, cost-effective and high-performing domestic manufacturing capabilities.
- ***Workforce development:*** to accelerate the development of an advanced manufacturing workforce.
- ***Sustainability:*** to support business models that help institutes become stable and sustainable.[113]

Types of intervention supported (How)

Manufacturing USA institutes have a primary emphasis on activities to facilitate the diffusion of knowledge and know-how. Each institute provides shared facilities to local start-ups and small manufacturers to help them scale up new technologies, accelerate technology transfer to the marketplace and facilitate the development of workforce skills in innovation.[114]

Activities include, for example:

The creation of industrial networks by:

- Easing connections (space sharing, matching companies, promoting partnerships);
- Performing an intermediary role between industry and academia;
- Promoting alignment to technical standards;
- Incentivising collaboration commitment between stakeholders by applying membership fees.

Developing system intelligence by:

- Building technology roadmaps.

Facilitating institutional development by:

- Creating standardised member and IP agreements.

However, institutes also support knowledge generation and deployment through a range of activities, including:

[112] Manufacturing USA (ND). How we work; Deloitte (2017). *Op. cit.;* Executive Office of the President National Science and Technology Council (2016). *National network for manufacturing innovation program. Annual report*.

[113] Executive Office of the President National Science and Technology Council (2016). *National network for manufacturing innovation program. Annual report*.

[114] AMNPO (2017). Manufacturing USA – the National Network for Manufacturing Innovation. Advanced Manufacturing National Program Office.

Knowledge generation by:

- Concept proofing and evaluating technology application feasibility;
- Validating concepts in a lab environment;
- Demonstrating prototypes in realistic environments.

Knowledge deployment by:

- Providing access to equipment and technical facilities;
- Assessing skill needs;
- Offering post-secondary internship and apprenticeship programmes;
- Coordinating industry-driven credentials/certifications.[115]

Coverage and impact

Manufacturing USA provides a support system for the stages of technology development and technology demonstration in which each of the 14 advanced manufacturing institutes has received federal funding for an amount between USD 55 million and USD 110 million. This funding has been matched with non-federal resources (local governments and other key partners) for an amount between USD 55 million and USD 502 million.[116]

The institutes operate at regional level to take advantage of area-specific industrial clusters, but Manufacturing USA aims to translate the institutes' technology and process learning to manufacturers at national level, and to bring together the institutes around jointly learnt lessons.

A total of 1,174 organisations participate in Manufacturing USA, including SMEs and large multinational conglomerates, academia, not-for-profit organisations and federal agencies.[117]

The 14 institutes that came into operation by December 2017 are:[118]

- The National Additive Manufacturing Innovation Institute (America Makes);
- Digital Manufacturing and Design Innovation Institute (DMDII);
- Lightweight Innovations for Tomorrow (LIFT) Institute;
- American Institute for Manufacturing Integrated Photonics (AIM Photonics);
- America's Flexible Hybrid Electronics Manufacturing Institute (NextFlex);
- Institute for Advanced Composites Manufacturing Innovation (IACMI);
- The Next Generation Power Electronics Manufacturing Innovation Institute (PowerAmerica);
- Clean Energy Smart Manufacturing Innovation Institute (CESMII);
- Reducing Embodied-energy and Decreasing Emissions (REMADE) Institute;
- Advanced Robotics for Manufacturing (ARM) Institute;
- Advanced Functional Fabrics of America Alliance (AFFAA);
- Advanced Regenerative Manufacturing Institute (ARMI);
- Rapid Advancement in Process Intensification Deployment Institute (RAPID);

[115] Deloitte (2017). *Op. cit.*
[116] ARMI (2016). ARMI in the news; Carnegie Mellon University (2016). $250 Million To Support Advanced Robotics Venture Led by CMU; CESMII (ND). Website; Executive Office of the President, National Science and Technology Council – Advanced (2016). *National network for manufacturing innovation program. Annual report*; Tech Times (2016). Public Private Consortium Pours $317 Million For Advanced Functional Fibers of America: What The Project Is About; Department of Energy (2016). Energy Department Announces American Institute of Chemical Engineers to Lead New Manufacturing USA Institute; NIST (2016). Fact Sheet: Commerce Secretary Pritzker Announces New Biopharmaceutical Manufacturing Innovation Hub in Newark, DE.
[117] Deloitte (2017). *Op. cit.*
[118] Manufacturing USA (ND). *How we work.*

- National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL).

Success stories

The institutes have been successful in achieving technology scale-up and transfer goals for particular applications, as exemplified by the following case studies:

- ***Facilitating breakthroughs in the creation and commercialisation of cutting-edge technology.*** With support from PowerAmerica, the company AgileSwitch has applied a new patented switching technique to provide enhanced control in high-power silicon carbide applications. AgileSwitch's technology has been incorporated into the company's first silicon carbide gate drive assembly, which has applications for solar inverters, wind turbine technology, electric vehicles and other clean energy applications. The institute is also helping the company generate interest in the product from customers at the university, government lab and industrial levels.
- ***Multi-project wafer creates economies of scale for photonics experimentation.*** AIM Photonics' multi-project wafer programme allows companies to produce photonics-enabled semiconductors at an extremely discounted cost compared to in-house production. By pooling demand, AIM Photonics creates the economies of scale needed to efficiently produce photonics-enabled semiconductors, significantly decreasing the cost barriers to experimenting with photonics.[119]

Key delivery stakeholders (Who)

The Manufacturing USA network is operated by the inter-agency Advanced Manufacturing National Program Office (AMNPO), which is headquartered in the National Institute of Standards and Technology (NIST), in the Department of Commerce. The office operates in partnership with the Department of Defense, the Department of Energy, NASA, the National Science Foundation, and the Departments of Education, Agriculture and Labour. Institutes are public–private partnerships, sponsored by government agencies, but industry-focused and led by executives with strong backgrounds in manufacturing.[120]

The programme's governance not only allows each institute to have autonomy from government to meet the needs of its members, but also provides enough oversight to ensure that overall goals are reached. Institutes have achieved a high degree of network connectivity and strong member recruitment .[121]

Key insights of the programme

The Manufacturing USA institutes intend to address information and network failures by linking SMEs to larger firms, backed by multidisciplinary university applied science and engineering departments. A key feature of this programme is the coordination function performed by the inter-agency Advanced Manufacturing National Program Office (AMNPO), which operates the programme and ensures correct coordination between relevant government stakeholders and the 14 advanced manufacturing institutes. Beyond coordination, the strong industrial background

[119] Deloitte (2017). *Op. cit.*
[120] Manufacturing USA. *Program details*. Deloitte (2017). *Op. cit.* Executive Office of the President National Science and Technology Council (2016). *Op. cit.*
[121] Deloitte (2017). *Op. cit.*

of institute executives represents an effort to ensure that these remain relevant to industrial needs, facilitating the task of recruiting industrial members into their network. The industrial vocation of the institutes is evidenced by their workforce development role, which includes post-secondary internship and apprenticeship programmes specifically tailored to meet the needs of their member firms.

Made in China 2025 – innovation centres

Overview

Made in China 2025 is a long-term development plan that was launched in 2015. It integrates a great number of previously uncoordinated initiatives to promote Chinese smart manufacturing, focusing on innovation, quality, digitalisation and sustainability. Made in China 2025 includes plans to set up a manufacturing innovation platform formed by national and provincial innovation centres that build on recent Chinese policies and explore new models of industrial innovation via strategic alliances where manufacturing companies lead the projects. The Made In China innovation centres are expected to focus on boosting technology and innovation in areas such as next-generation ICT, smart manufacturing, new materials, additives and pharmaceuticals, among others.

The first National Manufacturing Innovation Centre, launched in 2016, was the National Power Battery Innovation Centre (NPBIC). Other centres already established or approved are: the National High-speed Train Technology Innovation Centre (approved in 2016); the National Additive Manufacturing Innovation Centre (established in 2017); the Changshu Innovation Centre for Green & Intelligent Manufacturing (established in 2017); the National Information Photoelectron Innovation Centre (approved in 2017); the National Innovation Centre for New Energy Vehicles (approved in 2018); and the Henan Agricultural Machinery Innovation Centre (approved in 2018).

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			●
	Coordination failures			●
	Existence of public good		●	
WHAT Policy goal	Technology development			●
	Industrial competitiveness			●
	Societal challenges/needs	●		
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)			●
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)			●
WHO Key delivery stakeholders	National			●
	Regional			●
	Municipal/local		●	

Policy rationale (Why)

The aim of the National Manufacturing Innovation Centres, promoted by the Made in China 2025 strategy, is to address mainly information, coordination and network failures, with the intention of strengthening the role of industry in defining research and development priorities.

According to the "Guidelines for Construction and Implementation of Manufacturing Innovation Institutes (2016–2020)", with the innovation centres the Chinese government aims to "pool innovation and research resources; establish collaboration mechanisms; facilitate technology transfer and diffusion to commercial applications; improve innovation capacities; and further improve the enterprise-centred, market-oriented, industry–academia research on manufacturing". [122]

Policy goals (What)

The policy impact goal of the innovation centres is to upgrade Chinese manufacturing industry from "Made in China" to "Designed in China", mainly by promoting domestic technological development and absorption. By doing this, the programme aims to improve the nation's industrial competitiveness by helping the Chinese industrial sector to transition from low-value-added to high-value-added activities.

In particular, the innovation centres appear to reflect on the following themes:

- Attention to manufacturing scale-up, focusing on building a critical mass of multidisciplinary engineering R&D capabilities to accelerate the industrialisation of key generic industrial technologies.
- Efforts to deploy a greater range of scientific and technological resources to address industry-relevant engineering R&D challenges by building stronger linkages and alliances between universities and firms, but also public research institutes.
- The flexibility and freedom to experiment with organisational models for effective industry–academia research cooperation.

A number of priority sectors included in this initiative are: ICT; numerical control tools and robotics; aerospace equipment; ocean engineering equipment and high-tech ships; railway equipment; energy-saving vehicles; power equipment; agricultural machinery; new materials; biological medicine and medical devices.[123]

Types of intervention supported (How)

In August 2016 the Ministry of Industry and Information Technology, the Development and Reform Commission, the Ministry of Science and Technology and the Ministry of Finance released the "Guidelines for Construction and Implementation of Manufacturing Innovation Centres (2016–2020)".[124] These consider four basic principles:

Government guiding role: national and local authorities are responsible for developing overall plans for coordinating the construction of the innovation centres.

Market-oriented and collaborative construction: centres should involve industry-

[122] Chinese Government Portal (2016). *The Ministry of Industry and Information Technology has issued the Guiding Opinions on Improving the Manufacturing Innovation System and Promoting the Construction of Manufacturing Innovation Centers.*

[123] Tekes (2017). *Op. Cit*.

[124] Chinese Government Portal (2016). The Ministry of Industry and Information Technology has issued the Guiding Opinions on Improving the Manufacturing Innovation System and Promoting the Construction of Manufacturing Innovation Centers.

leading enterprises, universities and research institutes.

Local and regional context consideration: plans should consider local and regional contexts to achieve "differentiated development".

Initial pilots and orderly development: pilot projects were carried out based on the agglomeration of innovative resources such as "Made in China 2025 Pilot Cities", the "National New Industrialisation Demonstration Base" and the "National Hi-Tech Industrial Development Zone" to promote the construction of manufacturing innovation institutes in an orderly manner.

The Made in China 2025 initiative aims to support interventions across all layers of the innovation system, from knowledge generation to diffusion and deployment. In this regard, some of the suggested functions for the innovation centres include:

Knowledge generation:

- Conduct industry-led research on key technologies and develop inter-industry integrated technologies to break the supply bottleneck of common technologies for industrial development and promote industrial transformation and upgrading.

Knowledge diffusion:

- Establish collaborative mechanisms for research, development and innovation between research centres, colleges, universities and enterprises.
- Encourage international cooperation and network linkages.
- Strengthen the development and adoption of technical standards.

Knowledge deployment:

- Promote the commercialisation of scientific and technological achievements through incubation support and assistance, seed project financing, equity, rewards, and so on.
- Provide multi-level innovation training.[125]

Examples of innovation centres approved or established:

The Made in China 2025 goal is to reach 15 National Manufacturing Innovation Centres by 2020, which will be further increased to 40 by 2025. A brief overview of some of the centres that have already been established or approved is given below, as follows:

- The first National Manufacturing Innovation Centre was ***launched*** in 2016, corresponding to the National Power Battery Innovation Centre (NPBIC). The NPBIC's mission is to accelerate the industrialisation of innovative battery technologies and enhance the competitiveness of China's power battery industry, not only through R&D but also by providing testing services, pilot-scale experiments and industry support services.[126] The leading role in this centre has been taken by the China Automotive Battery Research Institute (CABRI), jointly established by domestic scientific research institutions, power battery manufacturers and automobile OEMs. The shareholders of CABRI include 11 enterprises of the General Research Institute for Nonferrous Metals (GRINM), China Ting New Power,

[125] Chinese Government Portal (2016). *The Ministry of Industry and Information Technology has issued the Guiding Opinions on Improving the Manufacturing Innovation System and Promoting the Construction of Manufacturing Innovation Centers.*

[126] Leal-Ayala *et al.* (2017). *Shaping national centres of excellence for Trinidad and Tobago. Design Principles and Next Steps for Implementation.* University of Cambridge, Policy Links.

FAW, Dongfeng, Chang'an, SAIC, Brilliance, GAC, CATL and Tianjin Lishen.[127]

- The National Additive Manufacturing Innovation Centre was the second National Manufacturing Innovation Centre to be ***launched***. It was established by the Xi'an Additive Manufacturing Research Institute in 2017, with initial funding of CNY 200 million (USD 31.2 million), in addition to provincial-level support funds. It will focus on the aviation, automotive and health-care sectors.[128]

- The National Information Photoelectron Innovation Centre was the third National Manufacturing Innovation Centre to be formally ***approved***. It will be located in the Province of Hubei. This project is led by Wuhan Optics Valley Opto-Electronic Innovation Centre. Other actors involved are FiberHome, Hengtong photoelectric, domestic enterprises and R&D institutions.[129]

- On 5 September 2016 the construction of the National High-speed Train Technology Innovation Centre was ***approved***. It will be promoted by the Ministry of Science and Technology and the State-owned Assets Supervision and Administration Commission of the State Council (SASAC).[130]

- In 2017 the Changshu Innovation Centre for Green & Intelligent Manufacturing was ***established***. This centre aims to promote the commercialisation of R&D and technical results, develop human resources, and promote industry through collaboration with foreign companies, particularly Japanese companies, universities and research institutes.[131] This centre is co-sponsored by the Changshu National Hi-Tech Industrial Development Zone and Mitsubishi Heavy Industries (Mitsubishi Electric). Other actors involved are universities, colleges and other high-tech enterprises.[132]

- On 4 January 2018 government entities of Henan Province (Development and Reform Commission, Science and Technology Department, Department of Finance) announced the ***approval*** of the Henan Agricultural Machinery Innovation Centre. This innovation centre will be led by the China YTO Group; Luoyang Branch Kelon Innovation and Technology; Zoomlion Heavy Machinery; Tianjin Research Institute; Tsinghua University; Northwest A & F University; and Henan University of Science; among other research institutes. The project started with initial funding of CNY 15 million (USD 2.3 million).[133]

- On 11 January 2018 the Ministry of Science and Technology ***approved*** the construction of the National Innovation Centre for New Energy Vehicles in Beijing. Beijing Automotive Group and Beijing New Energy Automobile will play a leading role. This innovation centre will report to both the Beijing Municipal Government and the

[127] ABAT. *About CABRI.*
[128] Chinese Government (2017). *The second national manufacturing innovation center settled in Shaanxi*
[129] CNHAN (2017). *Ministry of Industry official reply: Wuhan agreed to build a National Information Optoelectronics Innovation Center*.
[130] Chinese Government Portal (2018). *National High-speed Train Technology Innovation Center settled in the first batch of projects*.
[131] Mitsubishi (2017). *Press information*.
[132] Kongzhi (2017). *Changshu Green Intelligent Manufacturing Technology Innovation Center was formally established.*
[133] Chinese Government Portal (2018). *Henan Province, the first manufacturing innovation center was established*.

Ministry of Science and Technology, which will also provide support and play a coordination role.[134]

Key delivery stakeholders (Who)

The main national entities involved in the development of the innovation centres are the Ministry of Industry and Information Technology and the Ministry of Science and Technology. In both national and provincial centres, the Chinese government ensures that private sector companies play a leading role. Provincial and municipal authorities perform a relevant role in promoting and coordinating the establishment and future operation of the centres. Furthermore, Provincial Manufacturing Innovation Centres with a focus on national priority areas can later be upgraded to National Manufacturing Innovation Centres.[135]

Key insights of the programme

The National Manufacturing Innovation Centres promoted by the Made in China 2025 strategy aim to address mainly information, coordination and network failures, with the intention of strengthening the role of industry in defining research and development priorities. In contrast to similar centres in developed countries, a key characteristic of the Made in China 2025 innovation centres is their stated aim to help upgrade the Chinese manufacturing industry from "Made in China" to "Designed in China". They aim to do this by paying attention to manufacturing scale-up, focusing on building a critical mass of multidisciplinary engineering R&D capabilities to accelerate the industrialisation of key generic industrial technologies. Efforts to address industry-relevant engineering R&D challenges are characterised by a focus on building stronger linkages and alliances between universities, firms and public research institutes. Hence, the centres aim to fulfil a key networking function between distinct actors of the innovation system. Furthermore, they pay special consideration to local and regional contexts to achieve "differentiated development", supported by an active effort from national and regional authorities to ensure that private sector companies play a leading role in the development of the centres.

[134] Chinese Government Portal (2018). *Letter from the Ministry of Science and Technology on Supporting the Construction of a National Innovation Center for New Energy Vehicles*.

[135] Chinese Government Portal (2016). *The Ministry of Industry and Information Technology has issued the Guiding Opinions on Improving the Manufacturing Innovation System and Promoting the Construction of Manufacturing Innovation Centers.*

SME Capability-building

3.5 Hollings Manufacturing Extension Partnership – USA
3.6 Singapore Institute of Manufacturing Technologies, SIMTech – Singapore
3.7 Innovation & Capability Voucher (ICV), SPRING – Singapore

Hollings Manufacturing Extension Partnership

Overview

The Hollings Manufacturing Extension Partnership (MEP) is a successor of the Manufacturing Technology Centers Program, developed in 1989 in response to the perceived decline in position of the United States in comparison to Japan. The MEP network provides technical expertise to small manufacturers, strengthens capabilities across supply chains and promotes collaboration between suppliers. The MEP has nearly 600 offices and centres located across all 50 US states and Puerto Rico.[136]

The MEP funding model is a public–private partnership. Its partners include non-profits, state government agencies and universities. More than 1,200 experts work with manufacturers to help them improve their processes and identify opportunities to adopt new technologies or take new products to market. Over 25,000 manufacturers were served by the MEP in the fiscal year 2016. The MEP's services include: supplier improvement and supply chain optimisation, supplier scouting and business-to-business networks, and supply chain technology acceleration.[137]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures		●	
	Coordination failures			●
	Existence of public good		●	
WHAT Policy goal	Technology development	●		
	Industrial competitiveness			●
	Societal challenges/needs		●	
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)		●	
	Knowledge diffusion (*linkages & institutions*)		●	
	Knowledge deployment (*firm capability*)			●
WHO Key delivery stakeholders	National			●
	Regional			●
	Municipal/local			●

[136] National Academy of Science (2013). *21st Century Manufacturing. The Role of the Manufacturing Extension Partnership Program*. The National Academies Press.
[137] NIST – MEP (2017). *Impacts.*

Policy rationale (Why)

The Omnibus Trade and Competitiveness Act of 1988 created the Manufacturing Extension Partnership (MEP) programme to improve the competitiveness of US-based manufacturing by making manufacturing technologies, processes and services more accessible to small and medium-sized manufacturers. [138] MEP centres focus on providing US manufacturers with the information and tools they need to improve productivity, assure consistent quality, accelerate the transfer of manufacturing technology and infuse innovation into production processes and new products.[139]

Policy goals (What)

The MEP aims to enhance the productivity and technological performance of manufacturer SMEs.[140]

Types of intervention supported (How)

Customise services and funding of projects involving:

- ***Knowledge generation***
  - Product development and prototyping.
- ***Knowledge diffusion***
  - Technology scouting and transfer;
  - Supply chain development;
  - Technology-driven market intelligence.
- ***Knowledge deployment***
  - Lean and process improvements;
  - Workforce development.[141]

Coverage and impact

The MEP was assigned a budget of USD 130 million for Fiscal Share 2016, with cost share requirements for centres. In 2015 the national network of MEP centres interacted with 29,101 manufacturers to improve their performance, which represent 11.7 per cent of US manufacturer SMEs.[142]

In the fiscal year 2016, the MEP claims to have supported:

- USD 9.3 billion in sales;
- USD 3.5 billion in total investment in US manufacturing;
- USD 1.4 billion in savings;
- 86,602 jobs.[143]

For every dollar of federal investment the MEP national network estimates that:

- USD 17.9 are generated in new sales growth for manufacturers and USD 27 in new client investment. This translates into USD 2.3 billion in new sales annually.
- One manufacturing job is created or retained.[144]

Success stories

- Lumetrics. This company develops and manufactures non-contact optical inspection systems for the medical, glass, food packaging, ophthalmic, automotive and film industries. With the support of the New York Manufacturing Extension Partnership, Lumetrics was provided with testing services for a new non-contact metrology instrument. The company later obtained the CE Mark technical construction file, required for exporting devices to Europe. Windshield

[138] MEP Advisory Board (2016). Annual report.
[139] NIST (2017). MEP National Network Strategic Plan 2017-2022.
[140] National Academy of Science (2013). *21st Century Manufacturing. The Role of the Manufacturing Extension Partnership Program*. The National Academies Press.
[141] NIST (2017). How the network helps.
[142] NIST (2016b). The power to transform US Manufacturing. United States Census Bureau (2016). *2014 SUSB Annual Data Tables by Establishment Industry.*
[143] NIST – MEP (2017). Impacts
[144] NIST-MEP (2017). Who we are.

manufacturers and performance film manufacturers across Europe are now using Lumetrics instruments for their product testing.

- Precision Engineering, Inc. (PEI). A manufacturer specialising in custom metal components, enclosures and electro-mechanical assemblies. With the support of the Massachusetts Manufacturing Extension Partnership, PEI developed an interconnected quality and environmental management system to meet certification requirements. Now that it has the AS9100C certification, PEI can bid on aerospace-type productions. The company has increased sales and its workforce.[145]

Key delivery stakeholders (Who)

- The MEP is part of the National Institute of Standards and Technology (NIST), an agency of the US Department of Commerce.[146]
- The MEP is a public–private partnership, designed as a cost-share programme. Federal appropriations pay one-half, with the balance for each centre funded by state/local governments and/or private entities, plus client fees.[147]
- Partners:
  - State and local governments;
  - Federal government agencies, departments, programmes and laboratories;
  - Universities, community colleges and technical schools;
  - Trade associations;
  - Professional societies;
  - Industry leaders and think tanks;
  - Economic development organisations.[148]

Key insights of the programme

The MEP network provides technical expertise to SMEs across the country to increase the competitiveness of US manufacturing. The programme focuses primarily on knowledge deployment, with some emphasis on knowledge generation and diffusion. Examples of support provided include product development and prototyping, technology-driven market intelligence, and workforce development, although part of the National Institute of Standards and Technology (NIST), the funding model of the MEP network, is based on a public–private partnership. Based on the latest data, the return on investments generated through the programmes is remarkable. In 2016 the MEP network assisted 11.7 per cent of US manufacturer SMEs, and for every US dollar of federal investment, programmes generated USD 17.9 in new sales growth for manufacturers and USD 27 in new client investment, and one job was created or retained.

[145] NIST (2017). Manufacturing Successes in America.
[146] NIST (2016). *NIST MEP Annual Report* 2016.
[147] NIST (2017). About NIST-MEP.
[148] NIST (2017). Partnerships.

Singapore Institute of Manufacturing Technology, SIMTech

Overview

The Singapore Institute of Manufacturing Technology (SIMTech) is a research institute of the Agency for Science, Technology and Research (A*STAR). SIMTech was launched in 1993 as the first A*STAR Science and Engineering research institute. The institute works with over 1,300 companies (multinational companies, local companies, SMEs and start-ups) on industry and service projects. Several of these companies have become their long-term partners in technology development.[149]

SIMTech comprises four research and innovation centres: Manufacturing Productivity Centre (MPTC), Precision Engineering Centre of Innovation (PE COI), Sustainable Manufacturing Centre (SMC) and Emerging Applications Centre (EAC). In addition to R&D and innovation, SIMTech provides support to consortia projects, technology licensing, capability upgrading and roadmapping. Over 60 per cent of the companies supported by SIMTech are SMEs.[150]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures		●	
	Coordination failures			●
	Existence of public good			●
WHAT Policy goal	Technology development			●
	Industrial competitiveness			●
	Societal challenges/needs	●		
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)			●
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)			●
WHO Key delivery stakeholders	National			●
	Regional	●		
	Municipal/local	●		

[149] SIMTech (2013). *Our R&D journey for industry*.
[150] SIMTEch (2017). *Industry Collaborations*; SIMTech (2013), *Our R&D journey for industry*.

Policy rationale (Why)

SIMTech activities address system failures such as information and coordination failure. It is assumed that there is no perfect information at the level of the individual firm, and that the available information is not always understood. Firms can, however, learn. On the other hand, provided that industries are interdependent, it might be necessary for the government to coordinate the operations of various industries for the purpose of economy-wide productivity growth.[151]

SIMTech funds R&D projects, but its focus is on facilitating the diffusion and deployment of that knowledge. In particular, SIMTech "develops high value manufacturing technology and human capital to enhance the competitiveness of Singapore's manufacturing industry".[152]

SIMTech's roles are to:

- Boost the human capital base in Singapore through manpower development initiatives such as industry research collaborations and training programmes for industry.
- Generate, apply and commercialise R&D, advanced manufacturing science and technology through creating intellectual capital to enhance local industries' competitiveness.
- Enrich the industrial capital base from the outcome of R&D collaborations with industry and the transfer of research results through technology training.[153]

To date, SIMTech has completed over 5,300 projects in collaboration with industry in sectors such as aerospace, automotive, electronics and semiconductors, logistics, medtech, marine, oil and gas, and precision engineering.[154]

Types of intervention supported (How)

Some of the programmes and services that SIMTech provides for SMEs are:

Knowledge diffusion

- Consortia/collaborative industry projects (CIPs). These projects accelerate the adoption of technologies by sharing resources and expertise with groups of industry and research partners with similar technology needs.[155]
- Technology licensing. SIMTech licenses technology to local enterprises and multinational corporations through Exploit Technologies Pte Ltd, the commercialisation arm of A*STAR.[156]
- Operation and technology roadmapping (OTR). Through OTR, SIMTech helps SMEs to establish a long-term growth strategy driven by technology.[157]

Knowledge deployment

- Technology for enterprise capability upgrading (T-Up). This is a platform to directly assist SMEs to innovate and develop new capabilities and knowledge in order to increase their productivity and competeiveness. T-Up is a multi-agency effort that involves seconding research scientists and engineers (RSEs) to local enterprises for up to two years.[158]

[151] See Chang, H-J, Hauge, J., & Irfan, M. (2016). Theories of industrial policy.
[152] SIMTech (2017). *About us*.
[153] SIMTech (2017). Ibid.
[154] SIMTEch (2017). *Industry Collaborations*.
[155] SIMTech (2017). *Consortia-CIPs*.
[156] SIMTech (2017). *Technology Licensing.*
[157] SIMTech (2017). *OTR*.
[158] SIMTech (2017). *T-Up*.

Coverage and impact

Since SIMTech was set up in 1993, it has supported over 5,300 projects involving more than 1,300 companies, 65 per cent of which are SMEs.[159]

Outcome measures (1993–2000):

- SIMTech has licensed technologies to over eighty companies, of which the majority are local SMEs.
- Over SGD 188 million (USD 142.5 million) in funding from industry.[160]

Success stories

- Collaborative industry project (CIP) on 3D Additive Manufacturing Capabilities of Metal and Polymer. This project was designed to demonstrate 3D AM process capabilities, walking the participants through design to process optimisation, material preparation and handling, product processing to secondary operations. With the support of the Precision Engineering Centre of Innovation (PE COI), project participants from both local SMEs and MNCs used this CIP for the adoption and commercial use of 3D AM technology while leveraging SIMTech's know-how and facilities.[161]

- T-Up project: Resin & Pigment Pte Ltd. An SME that manufactures customised polymers for industrial applications. Researchers from SIMTech helped the company to set up research and testing facilities, as well as processes to manufacture new polymer material for industry, leading to the successful registration of a product patent. With improved capabilities, an expanded range of materials and service offerings, Resin & Pigment managed to clinch a major project with a multinational corporation to become the first contracted compounder in Asia, the products of which will be applied to automotives. The company also gained business growth in regional markets in China and India.[162]

Key delivery stakeholders (Who)

The Singapore Institute of Manufacturing Technology (SIMTech) is a research institute of the Agency for Science, Technology and Research (A*STAR). The strategic direction of SIMTech is set by the Management Committee, headed by the executive director. At operational level, the Research Liaison Office (RLO), the Industry Development Office (IDO), the Knowledge Transfer Office (KTO), and the Corporate Affairs Office (CAO) formulate the policies and standard operating procedures that run the various key functions of the institute. The institute works with over 1,300 companies (multinational companies, local companies, SMEs and start-ups) on industry and service projects. Several of these companies have become their long-term partners in technology development.[163]

Key insights of the programme

SIMTech is a research institute of the Agency for Science, Technology and Research (A*STAR), a national agency of the government of Singapore. It comprises 4 research and innovation centres that work in partnership with over 1,300 companies, of which 65 per cent are SMEs. The goals of the institutes are to boost the human capital base, to generate, apply and commercialise R&D, and to enrich the industrial capital base. In this respect, the institute is active with programmes where resources and technology expertise are shared with groups of industry and research partners;

[159] SIMTech (2013). *Our R&D journey for industry*; SIMTEch (2017). *Industry Collaborations*.
[160] SIMTech (2013). *Our R&D journey for industry*.
[161] SIMTech (2017). *Consortia-CIPs*.
[162] SIMTech (2017). *T-Up*.
[163] SIMTech (2013). *Our R&D journey for industry*.

and technology is licensed to local enterprises and multinational corporations. Since its creation in 1993, SIMTech has supported over 5,300 projects, involving more than 1,300 companies.

Innovation & Capability Voucher (ICV)

Overview

The Innovation & Capability Voucher (ICV) is a scheme managed by SPRING Singapore, an agency under the Singaporean Ministry of Trade and Industry. The ICV consists of grants for SMEs in the form of SGD 5,000 (USD 3,800) vouchers to pay for consultancy and technology solutions services.

The scheme was launched in July 2012, with a budget of SGD 32 million (USD 24.2 million) to be spent over a four-year period. Originally the scheme included only consultancy services on innovation, productivity, human resources and financial management; however, in 2014 the ICV was extended to funding equipment and hardware; technical solutions; professional services; and design and renovation services. This extension also involved additional resources of SDG 10 million (USD 7.6 million).[164]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures		●	
	Network failures			
	Coordination failures		●	
	Existence of public good			●
WHAT Policy goal	Technology development	●		
	Industrial competitiveness			●
	Societal challenges/needs	●		
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)	●		
	Knowledge diffusion (*linkages & institutions*)		●	
	Knowledge deployment (*firm capability*)			●
WHO Key delivery stakeholders	National			●
	Regional	●		
	Municipal/local	●		

[164] Gateway Law Corporation (2014). *Innovation Capability Voucher Scheme*; SMEportal (2017). *Innovation & Capability Voucher (ICV).*

Policy rationale (Why)

ICVs address the gap between the social and private costs and benefits of upgrading the business capabilities (existence of public good) of SMEs. The organisation and operation of firms of different sizes are increasingly affected by emerging technologies. However, SMEs tend to show weaker absorptive capacity, for financial, skills and/or management constraints, failing to take advantage of the opportunities offered by new technologies. Schemes such as ICVs facilitate access to expertise and technologies, which otherwise would not be affordable for SMEs.

Policy goals (What)

ICVs focus on increasing business productivity through capability-building. Through ICVs SPRING Singapore claims to help SMEs[165] to:

- Upgrade and strengthen their core business operations through consultancy in the areas of innovation, productivity, human resources and financial management; and
- Adopt and implement pre-scoped integrated solutions to improve business efficiency and productivity .[166]

Types of intervention supported (How)

ICVs support knowledge deployment, facilitating access to expertise and technology through:

- Consultancy projects supporting capability areas, such as technology feasibility studies, implementing ISO certification, productivity improvement projects, implementing learning and development programmes.
- Integrated solutions, which are tried-and-tested, plug-and-play tools that help SMEs overcome common business challenges and achieve overall productivity gains.[167]

The ICV is valued at SDG 5,000 (USD 3,785), and each SME is entitled to a maximum of eight vouchers for consultancy projects and up to two for integrated solutions. The duration of each project should not exceed six months. Supportable cost categories that can be used with the ICV are:

- Equipment and hardware;
- Technical solutions and training;
- Design and renovation;
- Payroll and HR systems (biometric fingerprint, face recognition, etc.);
- CRM system.[168]

Consultancy service and solution providers need to be pre-qualified to assist SMEs in implementing ICV-supported consultancy and/or integrated solutions projects. SPRING Singapore publishes Call-for-Collaborations (CFC) for this purpose.[169]

Coverage and impact

In 2015, 19,500 enterprises used the Innovation & Capability Voucher (ICV) scheme.[170] The programme was assigned a budget of SDG 42 million (USD 31.8 million).[171]

Success stories

Company: Kah Hong Hardware Engineering

Outcome: ISO 9001 implementation

Benefits: Reduction in the number of incorrect delivery items to fewer than two a month.

[165] Have group annual turnover of not more than SDG 100 million (USD 75.7 million) or group employment size of not more than 200 employees.

[166] SPRING Singapore. *Innovation & capability voucher*.

[167] SMEportal (2017). *Innovation & Capability Voucher (ICV).*

[168] SPRING Singapore (2017). *ICV.*

[169] Ibid.

[170] SPRING Singapore (2016). *Annual report 2015/2016*.

[171] Gateway Law Corporation (2014). *Innovation Capability Voucher Scheme.*

Overall customer satisfaction rose to above 70 per cent, while customer complaints were reduced to just one a month. The company has attracted extra business from its current customers and new purchasers, and it expects to see its revenue rise between 5–10 per cent.[172]

Company: Local food company Han's
Outcomes: Investment in an enterprise resource planning (ERP) system; installation of an e-procurement system; installation of a mobile ordering and payment system to improve customer experience; adhering to standards such as ISO 9001 on quality management systems and ISO 22301 on business continuity management systems (BCM).
Benefits: 10 per cent increase in sales (2013–14); 40 per cent increase in labour productivity (2006–14).[173]

Key delivery stakeholders (Who)

SPRING Singapore manages the ICV scheme. SPRING Singapore is an agency under the Ministry of Trade and Industry. SPRING will merge with IE Singapore to form Enterprise Singapore in the second quarter of 2018.[174] Among the service providers there are Nanyang Polytechnic, Singapore Polytechnic, Precision Engineering Centre of Innovation (PECOI, SIMTECH) and Temasek Polytechnic.[175]

Key insights of the programme

Emerging technologies involve opportunities for increasing company productivity and competitiveness. However, absorptive capacity is not homogenous among all sectors and company sizes. SMEs tend to face different constraints that may impede them from taking full advantage of the opportunities presented by the new technologies. The Singaporean experience with innovation and capability vouchers is a good example of how to reduce the access barriers to expertise and technology.

The ICV is a programme that is fully funded by the government, but its implementation relies on services providers. These providers are pre-qualified to ensure they deliver quality consultancy services. Universities and research centres are part of the list of pre-qualified service providers. The ICV scheme allows follow-up of the projects, incentivising SME commitment while limiting "over-use" of the vouchers by the same companies. Another relevant characteristic of the ICV is its flexibility to adapt to the changes in SME capability needs, as the 2014 extension demonstrated. This extension involved not only additional resources, but also a broader scope to cover technological solutions.

172 SPRING Singapore (2017). *Inspiring Success*.
173 Ibid.
174 SPRING Singapore (2017). *About us.*
175 SPRING Singapore (2017). *ICV.*

R&D Collaborative network

3.8 Central Innovation Programme for SMEs (ZIM) – Germany
3.9 German Federation of Industrial Research Association (AiF) – Germany

Central Innovation Programme for SMEs (ZIM)

Overview

The Central Innovation Programme for SMEs (ZIM) was launched in 2008, with the aim of supporting SMEs to develop new, or improve existing, products, processes or technical services. The AiF Projekt GmbH[176] manages ZIM, on behalf of the Federal Ministry for Economic Affairs and Energy (BMWi). ZIM participates in IraSME, a network of ministries and funding agencies that manage national and regional funding programmes for cooperative research projects between SMEs.[177]

ZIM funds R&D projects, cooperation networks and market launches of the results of the R&D projects. ZIM funding is open to German SMEs of all technologies and sectors (up to 499 employees and fewer than EUR 50 million in annual turnover, or a balance sheet total of no more than EUR 43 million). The annual budget is over EUR 500 million (USD 612.2 million). ZIM has signed bilateral funding agreements with Alberta (Canada), Brazil, Finland, France, Japan, Singapore, South Korea, Sweden, Taiwan and Vietnam.[178]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures		●	
	Network failures			●
	Coordination failures			●
	Existence of public good			●
WHAT Policy goal	Technology development			●
	Industrial competitiveness		●	
	Societal challenges/needs			
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)			●
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)			
WHO Key delivery stakeholders	National			●
	Regional			
	Municipal/local			

[176] AiF Projekt GmbH is a wholly owned subsidiary of the Cologne-based German Federation of Industrial Research Associations "Otto von Guericke" e.V. (also known as simply AiF).
[177] BMWi (2015). Boosting innovation Central Innovation Programme for SMEs; AIF Project GmbH. Company portrait.
[178] BMWi (2015). *Op. cit.; BMWi (2017).* International Cooperation Through ZIM. Funding for transnational joint R&D projects.

Brazil–Germany bilateral agreement

The ZIM programme also funds cooperation projects between German organisations and their partners abroad. It finances only the German partners involved, meaning the foreign organisations must secure funding themselves. Financial support is provided for joint R&D projects that must involve at least one German company and one foreign partner working together to develop innovative technical products, services and industrial application processes with an eye towards commercialising them in their domestic and/or global markets.

There is mutual benefit for the countries involved: the new product/process/service should be innovative, have relevant market potential, technological risk and add value to the economies of both countries; the project should demonstrate adequate balance and complementarity between the two partners in relation to the R&D phases; the project should present a clear competitive advantage and differentiated value proposition as a result of cooperation between the participants of the two countries.

On 20 August 2015 the governments of Brazil (The Secretariat of Innovation and New Businesses in the Ministry of Industry, Foreign Trade and Services of Brazil – MDIC) and Germany signed a Joint Declaration of Intent on bilateral cooperation in research, development and innovation. The second and most recent call for proposals for R&D projects between German and Brazilian companies was launched on 28 November 2017. In line with the general guidelines of the ZIM cooperation projects, German partners are funded by the ZIM programme itself. Funding for Brazilian partners is provided by the following Brazilian institutions:

- The National Development Bank (BNDES);
- The Brazilian Industrial Research and Innovation Company (EMBRAPII);
- The State Foundations for Research Support (FAPs).

BMWi (2017). *International Cooperation Through ZIM. Funding for transnational joint R&D projects.*
Source: BMWi-MDIC (2017). *2nd Call for Proposals for Joint Research and Development (R&D) Projects between German and Brazilian Companies*.

Policy rationale (Why)

The programme's focus is on providing funding for R&D projects, market launch and cooperation networks.[179]

Policy goals (What)

The aim of ZIM is to "sustainably increase the innovative capacity and competitiveness of SMEs including craft businesses and independent professions". ZIM supports SMEs "to develop new, or to improve, existing products, processes or technical services and to commercialize them".[180]

The top five sectors funded are: production technologies; electrical engineering, measuring and sensor technologies; ICT;

[179] BMWi (2015). *Boosting innovation Central Innovation Programme for SMEs*.
[180] BMWi (2015). *Op. cit.*

materials; health research and medical technologies.[181]

Types of intervention supported (How)

Knowledge generation:

- Single projects (funding of R&D projects undertaken by a single SME).

Knowledge diffusion:

- Cooperation projects (funding of cooperative R&D projects between SMEs or SMEs and RTOs).
- Cooperation networks (funding of management of innovative company networks and R&D projects generated by them – with a minimum requirement of six German SME partners). In the first phase of funding, the interdisciplinary network management team is to develop the idea until it is ready to be implemented (technology roadmap). In the second phase, it is to organise the division of responsibilities for implementation and the marketing of the R&D results.

Knowledge deployment:

- Market launch of the results of the R&D projects.[182]

Conditions for grants:

- The funding for individual and cooperation projects is awarded as a non-repayable grant in the form of co-financing up to the following rates based on the eligible costs. Maximum funding rates for individual projects and cooperation projects are between 25 and 55 per cent. The maximum project costs that are eligible for funding are EUR 380,000 (USD 466,000) per company, and EUR 190,000 (USD 233,000) per research institute. The maximum support available for network management is EUR 380,000 (USD 466,000).
- Research institutes can claim 100 per cent of the eligible project costs.
- For market launch the maximum funding rate is 50 per cent, with a maximum amount of EUR 50,000 (USD 61,300).
- Public and private non-profit research and technology organisations (RTOs) acting as a cooperation partner of an SME are also eligible for ZIM funding.[183]

Coverage and impact

During the period 2015–17, 349 cooperation networks have been supported, in addition to 8,504 cooperation projects and 1,960 individual projects. The number of individual projects represents 0.5 per cent of the total number of German SMEs and 2.8 per cent of the manufacturing SMEs. These projects have received funding of approximately EUR 1,620 million (USD 1,986 million) during the same period.[184]

Impact measures

- From 2012 to 2015 the funded companies showed an average increase in their sales of nearly 12 per cent, while the number of employees rose by 15 per cent.
- More than half of the projects were carried out by small enterprises.

Innovative network projects

- Approximately 70 per cent of the companies were able to increase their sales from 2012 to 2015.

[181] BMWi – ZIM (2017). *Statistik*.
[182] BMWi (2015). *Op. cit.*
[183] BMWi (2015). *Op. cit.*
[184] Statistisches Bundesamt (Destatis) (2017). *Enterprises, persons employed, turnover, investments, gross value added: Germany, years, enterprise size, economic sections*; BMWi – ZIM (2017). *Statistik*.

- On average 0.5 jobs were created and 2.4 jobs were retained.
- Nearly 90 per cent of the companies intensified their cooperation with other companies.

Lessons learnt

- In individual projects the level of technical achievement was larger than in cooperative projects. This has been attributed to the higher complexity involved in cooperation projects.[185]

Success stories

Nanostructured coatings for abrasive and erosive stresses:

- Project participants: two companies and two universities were involved in the development of this technology: DURUM VERSCHLEISS-SCHUTZ GmbH; IBS Steinführer GmbH; University of Lausitz (FH), University of Applied Sciences; Clausthal University of Technology.
- Approved funding: EUR 645,064 (USD 790,943).
- Project period: 12/2009 to 10/2011.

Inspection system for automatic damage detection of containers:

- Project participants – cooperation between a German and a Finnish company: LASE Industrial Lasertechnik GmbH, Wesel; Visy Oy, Tampere.
- Turnover of approximately EUR 1.05 million (USD 1.3 million).
- Project period: 05/2014 to 10/2015.

Key delivery stakeholders (Who)

The Central Innovation Programme for SMEs (ZIM) is a national programme financed by the Federal Ministry for Economic Affairs and Energy and administrated by AiF Projekt GmbH.[186]

Key insights of the programme

The ZIM programme aims to support SMEs to develop new, or improve existing, products, processes or technical services; it is financed by Germany's Federal Ministry for Economic Affairs and Energy (BMWi). ZIM funds R&D projects, cooperation networks and market launches of the results of the R&D projects, thus focusing mainly on knowledge generation and diffusion. R&D funding may be allocated to single projects, cooperative projects between SMEs (or SMEs and RTOs), or funding of the management of innovative company networks and R&D projects generated by them – with a minimum requirement of six German SME partners. In this respect, during the period 2015–17, 349 cooperation networks, 8,504 cooperation projects and 1,960 individual projects were supported. As part of the ZIM programme, agreements aimed at funding joint R&D projects between German and foreign companies are also available.

185 Depner et al. (2017). *Wirksamkeit der geförderten FuE-Projekte des Zentralen Innovationsprogramm Mittelstand (ZIM). RKW Kompetenz-zentrum*; Vollborth et al. (2017). *Wirtschaftliche Wirksamkeit der Förderung von ZIM-NEMO-Netzwerken, Fokus: ZIM-NEMO-Netzwerke. RKW Kompetenz-zentrum*.

186 BMWi (2015). *Boosting innovation Central Innovation Programme for SMEs*; BMWi (2017). *International Cooperation. Through ZIM. Funding for transnational joint R&D projects.*

German Federation of Industrial Research Associations, AiF

Overview

AiF is Germany's leading national organisation for the promotion of applied R&D in SMEs. It was established in 1954 as an industry-driven organisation managing public programmes of the German federal government. AiF and its research associations seek to provide comprehensive support in R&D matters to help SMEs meet the challenges of technological change. The "AiF innovation network" consists of 100 industrial research associations representing 50,000 businesses, mostly SMEs. Each research association represents a certain business sector, mostly SMEs, from specific branches of the economy or fields of technology.[187]

In 2014 AiF disbursed around EUR 500 million (USD 611 million) of public funding, particularly on behalf of the Federal Ministry for Economic Affairs and Energy (BMWi). Since its foundation, AiF has disbursed more than EUR 10 billion (USD 12.2 billion) in funding for more than 200,000 research projects for SMEs.[188]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			●
	Coordination failures			●
	Existence of public good		●	
WHAT Policy goal	Technology development			●
	Industrial competitiveness		●	
	Societal challenges/needs	●		
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)			●
	Knowledge diffusion (*linkages & institutions*)			●
	Knowledge deployment (*firm capability*)	●		
WHO Key delivery stakeholders	National			●
	Regional	●		
	Municipal/local	●		

[187] AiF (ND). About AiF.
[188] AiF (2015). Research for SMEs – AiF at a glance.

Policy rationale (Why)

AiF activities address mainly information, network and coordination failures, facilitating collaboration between enterprises and research institutions. AiF works in the interface between government, industry and academia.

Policy goals (What)

AiF aims to "strengthen firm's innovation capacity through R&D – from pre-competitive research to the benefit of whole branches of the economy to the practical implementation of research results in individual firms".[189]

Funding is open to all sectors and technologies represented in AiF's 100 industrial research associations, which, in practice, means wide coverage across the economy. Preferred R&D focus: pre-normative standardisation; product standardisation; technical tools; environmental solutions; generic industry demand; basic and process technologies.[190]

Types of intervention supported (How)

AiF's focus is on knowledge diffusion. AiF promotes R&D for SME enterprises through the organisation of joint industrial research, networking between different stakeholders and the administration of governmental programmes. AiF's core activity is so-called "Industrial Collective Research". a funding mechanism that enables businesses to solve shared problems through applied research projects. The focus is on pre-competitive research to close the gap between basic research and industrial application. Research associations collect ideas for research projects and identify common research needs within an industrial branch or field of technology.[191]

After a research project has been completed, both research associations and institutes take part in the transfer and dissemination of results, for example, through publications, conferences, workshops, the training of employees, exhibitions or fairs. The results of collective research are available for all interested enterprises. The phase of competitive exploitation of results comes after the project has been completed and the results disseminated. Then individual companies may take up the results and adapt them to their specific needs.[192]

AiF coordinates the Collective Research Networking (CORNET). This initiative facilitates international cooperation on the basis of existing national and regional funding schemes. Funded projects should have a maximum duration of 24 months. CORNET is characterised by high success rates (~66%) and short time to contract. Results are also openly accessible for follow-up development in individual firms.[193]

Coverage and impact

In 2016 AiF disbursed EUR 532 million (USD 650 million) of public funding, particularly on behalf of BMWi:[194]

- Industrial collective research: 1,754 projects funded with EUR 139 million (USD 169.9 million).
- Central Innovation Programme for SMEs (ZIM): 2,167 new R&D projects, with a combined funding volume of EUR 393 million (USD 480.2 million), were initiated.[195]
- The main technology fields funded were nanotechnology; production technologies; materials technologies; electrical

[189] AiF (2015). Research for SMEs – AiF at a glance.
[190] AiF (ND). Collective Research.
[191] Ibid.
[192] Ibid.
[193] CORNET (2017). Guidelines for Applicants.
[194] AiF (2017). Zahlen | Daten | Fakten 2016.
[195] See Section 3.7.

engineering; and health research and medical technology.

- Industrial collective research – funding: approximately EUR 200,000 (USD 244,400) per project in 2013.[196]

Since 1954 AiF has disbursed more than EUR 10 billion (USD 12.2 billion) in funding for more than 200,000 research projects for SMEs.[197]

Success stories

Project: two-step laser coating to protect 3D surfaces, creating a thin layer and a smooth surface. The main market sector at which this project is targeted is the tooling industry (moulds, dies and special tools). Examples are extruder screws where a surface roughness of a few micrometres can be tolerated. Another field of application outside this sector are micro-coolers for diode lasers where thin layers of a conductive material have to be applied.

- Duration: 01/07/2015 to 30/06/2017.
- Participants from Germany: DVS-FV – Forschungsvereinigung Schweißen und verwandte Verfahren e.V. des DVS (Participating Association); Fraunhofer ILT – Fraunhofer Institute for Laser Technology (Research Performer).
- Participants from Belgium/Wallonia: CRIBC – Centre de Recherches de L`Industrie Belge de la Ceramique (Coordinating Association and Research Performer).

The Research Society for Pigments and Coatings (FPL) interlinks approximately forty members from major enterprises, SMEs, innovation and research institutions. The members represent the process chain of organic coating technology, from raw materials to finished coatings. FPL started its first CORNET project in 2009 and since then has obtained support for nine additional projects. The most recent are:

- 2015 to 2017 – DuraCoat:
- Criteria and guidelines for evaluation and selection of anticorrosive paint systems for steel structures;
- Countries involved: Germany, Poland.
- 2015 to 2017 – SIMOPOLI:
- Smart infrared curing for compact powder pre-coating lines;
- Countries involved: Germany, Belgium-Wallonia.
- 2016 to 2018 – IPOC:
- Improved powder coatings for offshore constructions;
- Countries involved: Germany, Belgium-Flanders, Belgium-Wallonia.[198]

Key delivery stakeholders (Who)

AiF is a non-profit association founded by a joint initiative of the government and industry. Each member (research association) of AiF represents a certain business sector, mostly SMEs, from specific branches of the economy or fields of technology. By joining a research association and taking an active part in its meetings and committees, SMEs influence AiF's research agenda and priorities.[199]

Stakeholders

- 100 industrial research associations representing approximately 50,000 businesses, mostly SMEs;
- 1,200 associated research institutes;
- AiF's affiliates in Cologne and Berlin
- Universities;
- Fraunhofer Institutes;
- International partners in Austria; Belgium (Flanders, Wallonia); Canada (Québec);

196 AiF (ND). Collective Research.

197 AiF (2015). Research for SMEs – AiF at a glance.

198 CORNET (2017). Success stories.

199 AiF (2015). Research for SMEs – AiF at a glance.

Czech Republic; Japan; Netherlands; Peru; Poland and Switzerland.[200]

Finance

AiF is an independent industrial federation, and its operation is financed entirely by industry. However, the association implements innovation programmes for SMEs, mainly from the Ministry for Economic Affairs and Energy. In addition, national and regional funding programmes form the basis of support with international partners in CORNET projects.[201]

Organisation

- General Assembly (*Mitgliederversammlung*).
  The members of AiF integrate the General Assembly, which is responsible for the election of Executive Committee members; the approval of annual accounts and the annual budget; among other tasks.
- Executive Committee (*Präsidium*). The Executive Committee is made up of 15 representatives, 6 from the General Assembly, 6 from the business community and 3 from the scientific community. They are nominated and elected by the General Assembly. Each representative is elected for a 3-year term, with the possibility of being re-elected for 3 more years. The president and vice presidents are elected within from the Committee members. The Executive Committee is in charge of the management of the association.
- Senate (*Senat*). Advisory and communication arm. The Senate is formed of at least ten members, who are representatives from the business community, the government and the scientific community. They are elected by the president of the association on the proposal of the Executive Committee. They are appointed for a period of three years.
- Scientific Council (Wissenschaftliche Rat). Provides advice to the Executive Committee, ensuring the quality of research and promoting knowledge and technology transfer. It is integrated by the heads and deputy heads of AiF's Expert Groups.[202]

Key insights of the programme

AiF has successfully engaged German SMEs in R&D and other innovation activities. One of the main achievements of AiF has been to become an umbrella organisation. SMEs tend to face resource constraints, it being difficult for them to have formalised innovation strategies. Having diverse research associations under one roof and promoting networking activities may reduce the burden and uncertainty of participating in R&D activities, as the German case shows.

The AiF case also represents an example of how non-governmental organisations can play an important role in bridging interests between industry and academia, facilitating the translation of knowledge and technology into commercialised solutions. The accountability of the Executive Committee to the General Assembly facilitates the articulation of a wide range of interests of their members to pursue common objectives, while preventing AiF from being captured by group interests. Moroever, AiF's proven experience in working with SMEs and the transparency in its organisation motivated the government to appoint the association to coordinate and implement public funded programmes since the late 1970s.

[200] AiF (ND). About AiF.
[201] AiF (ND). About AiF; CORNET (ND). About.
[202] AIF (2018). Satzung.

Skills development in disruptive technologies

3.10 SkillsFuture Singapore programmes at SIMTech – Singapore
3.11 NIBRT programmes – Ireland
3.12 KOMP-AD – Denmark

SkillsFuture Singapore programmes + SIMTech

Overview

Two of the main Singaporean agencies involved in capability-building on disruptive technologies are the Singapore Institute of Manufacturing Technology (SIMTech) and SkillsFuture Singapore (SSG), a statutory board under the Ministry of Education (MOE).

SIMTech's Knowledge Transfer Office (KTO) provides case-study-based training for manufacturing specialists, engineers and managers, as well as other industry professionals and executives.[203] In October 2016 the Singapore Workforce Development Agency (WDA) was reconstituted into two statutory boards: SkillsFuture Singapore (SSG) and Workforce Singapore (WSG). SSG coordinates the implementation of the SkillsFuture initiatives. SkillsFuture is a "national movement" to equip Singaporeans with the skills demanded by the rapidly changing economy. It comprises several initiatives on tech skills, for upgrading, updating or career conversions.[204] Several of these programmes are run in collaboration with WSG. WSG efforts are focused on helping workers to meet their career aspirations and secure quality jobs at different stages of life.[205]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			
	Coordination failures			●
	Existence of public good			●
WHAT Policy goal	Technology development	●		
	Industrial competitiveness			●
	Societal challenges/needs		●	
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)	●		
	Knowledge diffusion (*linkages & institutions*)		●	
	Knowledge deployment (*firm capability*)			●
WHO Key delivery stakeholders	National			●
	Regional		●	
	Municipal/local		●	

[203] A*STAR (2014). "Transforming SMEs", *Manufacturing Matters*, No. 2.
[204] SkillsFuture Singapore and Workforce Singapore (2017a). *About*.
[205] Ibid.

Policy rationale (Why)

The Singapore Institute of Manufacturing Technology (SIMTech) and SkillsFuture Singapore (SSG) address information and coordination failures. These system/market failures are particularly relevant to emerging technologies, where the demand for skills tends to move faster than the supply. Both SSG and SIMTech work in close collaboration with industry and provide information and training on tech skills demanded by the market.

SkillsFuture initiatives have an explicit focus on the challenges imposed by emerging technologies. The courses delivered within these initiatives address training needs at different stages of the career and from different types of job. This approach allows mid-career employees to equip themselves with the skills demanded by emerging technologies. The framework followed by SSG also involves awareness-raising and mentoring as part of its strategy to enhance technological adoption.

Policy goals (What)

The overall goal of the programmes summarised in this case study is to strengthen industry competitiveness, through capability-building. In particular, SSG involves four goals (key thrusts):

- Helping individuals to make well-informed choices in education, training and careers;
- Developing an integrated high-quality system of education and training that responds to constantly evolving needs;
- Promoting employer recognition and career development based on skills and mastery;
- Fostering a culture that supports and celebrates lifelong learning.[206]

Types of intervention supported (How)

SIMTech courses are industry-led and focused on precision engineering. SIMTech training is based on the R&D activities and collaborations between the research institute and over 1,300 companies.[207]

SkillsFuture follows a flexible, responsive, digital-focused and people-centred approach. SkillsFuture is defined as: *"A national movement to provide Singaporeans with the opportunities to develop their fullest potential throughout life, regardless of their starting points. Through this movement, the skills, passion and contributions of every individual will drive Singapore's next phase of development towards an advanced economy and inclusive society."*[208]

SkillsFuture programmes cover a variety of dimensions, from awareness courses on emerging skills at three different levels of proficency (SkillsFuture Series); mentoring (SkillsFuture Career Advisors Programme, SkillsFuture Advice, Education and Career Guidance, MySkillsFuture); place-and-train (P-Max) and training courses on digital technologies (SkillsFuture for Digital Workplace, TechSkills Accelerator).

Singapore Institute of Manufacturing Technology (SIMTech)

Some qualities of SIMTech's Knowledge Transfer Office (KTO) courses are: case-study-based curriculum, hands-on practical training combined with industry best practice insights, corporate classes customised to company-specific needs, access to cutting-edge technology and blended learning options combining expert classroom lectures and e-learning convenience.

[206] Ibid.
[207] A* STAR (2018). *Industry Collaborations.*
[208] SkillsFuture (2017d). *About SkillsFuture*.

The Precision Engineering (PE) Workforce Skills Qualifications (WSQ) programme is the core of the SIMTech's courses offer. This programme includes graduate diplomas, specialist diplomas and modular courses in fields such as additive manufacturing and precision engineering. In addition to these courses, SIMTech offers masterclasses in Predictive Manufacturing and Services and in Strategic Planning for Operational Excellence.[209]

Moreover, with the support of SkillsFuture Singapore, SIMTech launched the Manufacturing R&D Certificate (MRDC) Programme in 2015 to address skills gaps in advanced manufacturing.[210]

SkillsFuture Singapore (SSG)

One of the main programmes managed by SSG is the TechSkills Accelerator (TeSA). TeSA is a set of programmes designed to attract ICT professionals or help existing employees to upgrade and acquire new ICT skills. TeSA offers training opportunities through seven programmes:

- Company-Led Training (CLT) Programme. CLT helps fresh and mid-level professionals to acquire specialist, expert or mastery-level competencies for jobs in demand by the industry. It focuses on cyber security, artificial intelligence, data analytics, software development, the Internet of things and network and communication platforms.
- Critical Infocomm Technology Resource Programme Plus (CITREP+). This programme supports local ICT professionals in keeping pace with technology shifts through continuous and proactive training.
- National Infocomm Competency Framework (NICF). NICF is a national Infocomm roadmap, which articulates the competency requirements of key professionals.
- Professional Conversion Programme (PCP) for the ICT Sector. PCP helps ICT jobseekers to reskill and acquire the necessary knowledge and competencies to take on new jobs.
- SkillsFuture Earn and Learn Programme (ELP). ELP is a place-and-train programme for fresh graduates.
- SkillsFuture Study Award for the ICT Sector. This programme is for early and mid-career, allowing participants to develop and deepen their skills in future growth clusters in ICT.
- Tech Immersion and Placement Programme (TIPP). TIPP helps non-ICT professionals, especially from science, technology, engineering and maths (STEM), or other disciplines, to gain ICT skills. These professionals are placed into tech job roles after undergoing short, intensive and immersive training courses delivered by industry practitioners.[211]
- SkillsFuture for Digital Workplace. This is a national initiative that provides workers with the mindset and basic functional skills to prepare for the future economy. It consists of a two-day programme (up to 18 hours) on digital skills and emerging technologies.[212]

Coverage

By 2017, SIMTech-SSG had:

- Launched 22 WSQ training programmes;
- Trained more than 3,700 professionals, managers, executives and technicians;
- Awarded over 6,000 Statements of Attainment.

[209] A* STAR (2017b). Courses.
[210] A* STAR (2017c). *"Skills upgrading amidst disruptions"*, *Manufacturing Matters.*
[211] SkillsFuture (2017a). TESA.
[212] SkillsFuture (2017b). Digital Workplace.

- Over a thousand local manufacturing companies have benefited. Approximately 70 per cent of these are SMEs.
- Ten SSG masterclasses were conducted by internationally renowned experts on emerging innovative technologies.
- Over 300 participants have attended the masterclasses.
- Fifteen graduates from the Manufacturing R&D Certificate (MRDC) Programme.[213]

TechSkills Accelerator (TeSA):

- During the period 2016–17 TeSA enabled more than 16,000 ICT professionals to up-skill and re-skill themselves.[214]

Success stories

Company: Kulicke & Soffa Pte Ltd

- Course: PE WSQ Carbon Programme
- Testimony: "The PE WSQ Carbon Programme that aligns with our own Sustainability Steering Committee that looks to develop in-house sustainability champions within our company. Through this programme, our company has identified hotspots for improvement, with the potential to reduce our carbon footprint by 20% and significantly increase cost savings per year."[215]

Company: Hewlett Packard Enterprise Singapore Pte Ltd

- Course: Data mining
- Testimony: "One of the main challenges of estimating the ship-out date is the hardware function testing time, which varies with the configuration that the customer has ordered (…) Through applying what I have learnt during the course, my colleagues and I, with guidance from SIMTech's Mentor, were able to build a predictive model to predict the testing time based on the customer's configuration. By using the data mining methods, we are now able to predict the function testing time needed faster, with high accuracy of more than 90%. This [has] helped the company to provide a more accurate commitment date to the customer."[216]

Key delivery stakeholders (Who)

SIMTech's KTO training courses are conducted in close collaboration with SSG.[217] The Future Economy Council (FEC) oversees SSG initiatives. The FEC, chaired by the Minister for Finance, comprises members from government, industry, unions and educational and training institutions.[218] Several of the SSG programmes are run in collaboration with Workforce Singapore (WSG), which is a statutory board under the Ministry of Manpower (MOM) that promotes the development, competitiveness, inclusiveness and employability of all levels of the workforce. Its focus is on helping workers to meet their career aspirations and secure quality jobs at different stages of life. SPRING Singapore is another key partner of SSG. This government agency, under the Ministry of Trade and Industry, helps enterprises in financing; capability and management development; technology and innovation; and access to markets. SPRING Singapore provides funding for several SkillsFuture initiatives. In particular, the TeSa initiative is driven by the Infocomm Media Development Authority (IMDA) and in partnership with WSG and SSG.[219] The IMDA is a statutory board in the Singapore government, which promotes and

[213] A* STAR (2017c). *"Skills upgrading amidst disruptions"*, *Manufacturing Matters.*
[214] IMDA (2017). *TechSkills Accelerator*.
[215] A* STAR (2018). *Corporate testimonials.*
[216] Ibid.
[217] A*STAR (2014). "Transforming SMEs", *Manufacturing Matters*, No. 2.
[218] SkillsFuture (2017d). *About SkillsFuture*.
[219] SkillsFuture (2017a). *TESA*.

regulates the converging infocomm and media sectors.[220]

Key insights of the programme

Emerging technologies are likely to displace highly automated jobs, while creating new jobs and the related demand for new skills. These trends impose challenges on both employees and employers. SSG is an example of a policy designed in response to these emerging trends. SSG delivers a comprehensive strategy for skills development, including awareness-raising, mentoring and training on digital skills for different career stages. One of the key characteristics of SSG is its focus on people's careers, rather than solely on industry demands. This particular focus is derived from the approach previously followed by the Workforce Development Agency. Another relevant SSG strategy is the inclusion of the ICT skills conversion course.

SSG has developed synergies with different actors, for example: SIMTech, in the case of the Manufacturing R&D Certificate Programme; and the Infocomm Media Development Authority, in the case of TeSA. These synergies show the importance of having agencies such as SkillsFuture Singapore and Workforce Singapore, which work transversally on workforce development.

SIMTech's case, on the other hand, shows a longer-term approach, based on R&D. SIMTech has collaborated with industry for more than two decades and, consequently, the curricula of the courses delivered by the institute are industry-led and mainly specialised on precision engineering. The close relation between SIMTech and industry has allowed the institute to deliver highly practical courses.

[220] IMDA (2018). *What we do*.

The National Institute for Bioprocessing Research and Training (NIBRT) programmes

Overview

Opened in 2011, the National Institute for Bioprocessing Research and Training (NIBRT) is a global centre for training and research in bioprocessing. The NIBRT facilities in Dublin, Ireland (6,500m^2), were built to closely replicate a state-of-the-art bioprocessing plant, which allows trainees to experience practical skills-based training. The NIBRT provides a "one-stop-shop" for the bioprocessing industry's training requirements.[221]

The NIBRT was primarily funded by the government of Ireland through Ireland's inward investment promotion agency, IDA Ireland (Industrial Development Agency). It works as a partnership between University College Dublin, Trinity College Dublin, Dublin City University and the Institute of Technology, Sligo.[222]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			
	Coordination failures			●
	Existence of public good			●
WHAT Policy goal	Technology development	●		
	Industrial competitiveness			●
	Societal challenges/needs		●	
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)	●		
	Knowledge diffusion (*linkages & institutions*)		●	
	Knowledge deployment (*firm capability*)			●
WHO Key delivery stakeholders	National			●
	Regional	●		
	Municipal/local	●		

[221] NIBRT (2017). *Annual report 2016*.
[222] NIBRT (ND). *About NIBRT*.

Policy rationale (Why)

Placing all the bioprocessing courses in one institute, the NIBRT addresses information and coordination failures, which create gaps between the demand and supply of bioprocessing skills. Moreover, through free-of-charge courses the NIBRT also responds to the difference between the private and social costs and benefits (the existence of public good) of training on bioprocessing, one of the main industrial sectors in Ireland. By 2016 the biopharmaceutical industry in Ireland had accumulated a EUR 10 billion (USD 12.2 billion) investment, most of which has arrived in the last 10 years.[223] Moreover, this sector has shown the highest increase in net selling value among all the industrial sectors. The pharmaceutical sector showed an increase rate of 128.5 per cent during the period 2014–16.[224]

Policy goals (What)

The NIBRT's mission is to support the development of the bioprocessing industry in Ireland and to attract additional bioprocessing companies to Ireland by:

- Training highly skilled personnel for the bioprocessing industry;
- Conducting world-class research in key areas of bioprocessing;
- Providing a critical mass of multi-purpose bioprocessing facilities.[225]

Types of intervention supported (How)

NIBRT programmes focus on knowledge deployment. The primary component of NIBRT courses is their hands-on lab exercises.[226] NIBRT education programmes include:

- Undergraduate programmes;
- Master's programmes;
- Springboard courses. Free-of-charge courses at certificate, degree and Master's level. These courses are designed for people seeking employment or people in employment in the biopharmaceutical industry. Springboard courses are supported by leading organisations, including Alexion, Allergan, Amgen, BioMarin, Bristol Myers Squibb, Eurofins Lancaster Labs, IDA Ireland, Lilly, MSD, Nexvet, Pfizer, PPD, PharmaChemical Ireland and Regeneron.
- Certificates in science. Intensive training programmes focused on upgrading key competencies required in (bio)pharma manufacturing. These courses have been designed in association with companies such as Pfizer, Merck Sharp Dohme, Janssen Biologics and Eli Lilly and Co.[227]

As part of the NIBRT's strategy to attract talent, the institute includes in its promotion brochures and annual reports, information about jobs announcements and new investments in the industry.

Coverage

Activities performed and outcomes achieved in 2016 by the NIBRT:

- Over 18,500 learning days delivered to 4,000 trainees. Key clients included Abbvie, AB Sciex, Allergan, Amgen, Amneal, Bioclin, BioMarin, Bioreliance, Bristol Myers Squibb, CAI, Compliance Group, Eirgen, Eli Lilly and Co., Janssen Biologics, Merck Sharp Dohme (MSD),

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[223] NIBRT (ND). Education.; IDA Ireland (2018). Biopharmaceuticals.

[224] CSO (2017). *Irish Industrial Production by Sector*. http://www.cso.ie/en/releasesandpublications/er/iips/irishindustrialproductionbysector2016/

[225] NIBRT (2017). Annual report 2016.

[226] NIBRT (ND). Training methodology.

[227] NIBRT (ND). Education.

Mylan, Pfizer, Regeneron, Roche, Sanofi Genzyme, Sartorius Stedim Biotech, Shire, Thermo FisherScientific, 3M.

- The NIBRT partnered with 12 higher education institutes to deliver practical, experiential training to their students, including University College Dublin, Dublin City University, Institute of Technology Sligo, Trinity College Dublin, Dundalk Institute of Technology, Dublin Institute of Technology, Cork Institute of Technology, Institute of Technology Tallaght, Galway Mayo Institute of Technology, National University of Ireland Galway, University of Limerick and Limerick Institute of Technology.
- The NIBRT partnered with six higher education institutes to provide free training programmes to over 400 jobseekers under the Springboard+ programme. On average, 65 per cent of these trainees secured employment.
- International clients who travelled to the NIBRT to access the state-of-the-art pilot plant facilities included: AbbVie, 3M, Sartorius Stedim Biotech, Thermo Fisher Scientific, Bioreliance, AB Sciex, C Technologies, Mylan, TR Pharm and Janssen Biologics.[228]

Success stories

Merck Sharp Dohme (MSD) Brinny in Cork, Ireland.

- Company profile: centre for the manufacture and quality assurance of its biotechnology-based pharmaceutical products; over 400 employees.
- Training support: in September 2011 MSD Brinny, in association with the NIBRT, formed a partnership with the Institute of Technology, Sligo, to provide a ground-breaking educational training programme for the workforce. In total, 65 MSD employees completed education courses delivered primarily through online learning. The courses also featured practical work in the NIBRT's state-of-the-art training facilities and project work based on-site in MSD.
- Outcomes: in 2012 the MSD Brinny site won an Outstanding Achievement Award for its innovative partnership programme with the NIBRT and Institute of Technology, Sligo, from the Irish Institute of Training & Development (IITD) National Training awards.[229]

The NIBRT and GE Healthcare opened a new training centre, where up to 1,500 professionals are expected to receive training annually. The new centre will also support GE BioPark Cork, a GE-managed campus including four prefabricated, off-the-shelf biologics factories owned by independent biopharma companies manufacturing proprietary medicines. GE BioPark Cork is expected to be home to more than 500 new jobs when fully operational: 400 with biopharma companies; and a further 100 employed directly by GE.[230]

Key delivery stakeholders (Who)

The NIBRT is based on a collaboration between University College Dublin, Trinity College Dublin, Dublin City University and the Institute of Technology, Sligo. It was primarily funded by the government of Ireland through Ireland's inward investment promotion agency, IDA Ireland (Industrial Development Agency), which is responsible for the attraction and development of foreign investment in Ireland. The NIBRT operates in close collaboration with the industry.[231]

[228] NIBRT (2017). *Annual report 2016*.
[229] NIBRT (2013). *MSD (Brinny) Education Case Study NIBRT and IT Sligo.*
[230] NIBRT (2017). *Annual report 2016*.
[231] NIBRT (ND). *About NIBRT*.

Key insights of the programme

The Irish NIBRT experience is a success case of skills development in collaboration with the industry. It was funded as part of a broader strategy to attract foreign investment into the pharmaceutical sector. The NIBRT's key strategy was to replicate state-of-the-art manufacturing facilities to provide the right environment for quality training. This effort is supported by the R&D activities performed within the institute, which include contract research. Moreover, the NIBRT has worked as an umbrella organisation, gathering in one place research and training expertise from different Irish institutions.

The successful collaboration with the industry has allowed the NIBRT to keep a strong track record of candidates obtaining employment in the pharmaceutical sector. In addition to this prestige, Springboard's free-of-charge courses have also proved to be an efficient strategy to attract talent. Partnerships with higher education institutes and professional associations have also been crucial to matching skills demands from industry.

Competence Track for Automation and Digitalisation in SMEs (KOMP-AD)

Overview

Competence Track for Automation and Digitalisation in SMEs (KOMP-AD) was an education programme that operated between 2013 and 2015. KOMP-AD was launched by the Ministry of Business and Denmark's Growth Council in response to decreasing Danish competitiveness. The programme addressed the lack of knowledge and practical competencies in the field of automation and digitalisation. They assembled a nationwide consortium to develop and implement the project. KOMP-AD was established as a partnership between a total of 30 partners, covering Danish vocational schools and colleges, SMEs, business associations and public actors within business support.[232] The long experience of Danish vocational schools in engaging with SMEs on practical learning in the workplace facilitated working on digitisation and automation. Moreover, business schools contributed, developing new practice learning models, with the participation of industry associations and business promoters.[233]

The programme at a glance

		Minor emphasis	Some emphasis	Primary emphasis
WHY Policy rationale	Information failures			●
	Network failures			
	Coordination failures			●
	Existence of public good			●
WHAT Policy goal	Technology development	●		
	Industrial competitiveness			●
	Societal challenges/needs		●	
HOW Types of intervention supported	Knowledge generation (*basic and applied R&D*)	●		
	Knowledge diffusion (*linkages & institutions*)		●	
	Knowledge deployment (*firm capability*)			●
WHO Key delivery stakeholders	National			●
	Regional			●
	Municipal/local	●		

[232] Iris Group (2015). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers; Iris Group (2015b). *Evaluering af KOMP-AD*; European Social Fund (2017). Projects. *Technical training streamlines for success*.
[233] Iris Group (2015b). *Evaluering af KOMP-AD*.

Policy rationale (Why)

KOMP-AD addressed the mismatch between the demand and supply of skills in the field of automation and digitalisation. The rationale behind the programme was the recognition of the lower capacity among SMEs to deploy digital and automation technologies.

KOMP-AD provided a platform for key stakeholders to get involved in tailor-made competence development processes. The project was initiated in 2012 by three Zealand-based vocational schools, which organised a nationwide consortium, with the approval of the Ministry of Business and Denmark's Growth Council. The project was originally planned to run until 31 December 2014, but it was extended until June 2015.[234]

Policy goals (What)

KOMP-AD aimed to improve the productivity, growth and earnings of 250 SMEs by increasing their use of digital and automated solutions in products and services.[235]

Types of intervention supported (How)

KOMP-AD activities focused on knowledge deployment.

The courses consisted of three phases:

- Recruitment and screening of SMEs to identify companies with potential and challenges within automation and digitalisation;
- Initial problem identification and dialogue with SMEs;
- "Tailor-made" competency-development courses for employees.

Coverage and impact

The total budget of this project was EUR 5.7 million (USD 7 million), half of which was contributed by the European Social Fund.[236]

Impact indicators

From the participating companies (250 companies, from January 2013 to June 2015):

- 72 per cent have experienced some productivity improvement;
- 41 per cent have experienced an increase in revenue;
- 55 per cent have experienced an increase in profits.[237]

Success stories

VVS Løsning. This company collaborated with Learnmark Horsens to digitise workflow. The company chose to invest in iPads for all employees and to implement a cloud-based – ready time – and case management programme for craftsmen "Ordrestyring.dk".[238]

Key delivery stakeholders (Who)

Actors involved: vocational schools and colleges, SMEs, business associations, the Ministry of Business and Denmark's Growth Council.[239]

The region of Zealand played an important role in the development of this strategy. KOMP-AD was initiated in 2012 by three vocational schools based in this region. Moreover, the region provided complementary funding through existing schemes.[240]

Key insights of the programme

[234] Iris Group (2015b). *Evaluering af KOMP-AD*.
[235] Iris Group (2015a). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.
[236] Ibid.
[237] Iris Group (2015b). *Evaluering af KOMP-AD*.
[238] Ibid.
[239] Iris Group (2015a). *Digitalisation and automation in the Nordic manufacturing sector. Status, potentials and barriers*. Nordic Council of Ministers.
[240] VEU.Center (ND). *Vækst gennem digitalisering og automation.*

KOMP-AD's case is an example of a tailor-made programme designed to increase absorptive capacity among SMEs. The focus of the programme was on digitalisation and automation. This Danish experience shows how vocational schools can deliver training on emerging technologies, adapted to the particular needs of SMEs. An evaluation of the programme has provided evidence of a positive impact, especially on the productivity of the companies.[241] Moreover, the evaluation found a large amount of unexplored potential for increasing the digitalisation and automation levels of Danish SMEs. Approximately half of the participating companies indicated that they would not have taken part in any competence development course if they had not had the opportunity to join KOMP-AD.

[241] Iris Group (2015b). *Evaluering af KOMP-AD*.

4

Discussion and policy implications

This section reflects on the key policy implications emerging from the international review carried out during this project. The section attempts to synthesise key messages from previous sections of the report and highlight considerations and practices that appear to be particularly relevant to ensuring effective policy implementation in Brazil.

Agency coordination and formation of a common national vision around new technologies

The development, diffusion and deployment of technologies remain a priority for governments around the world. However, ensuring a common vision and alignment of efforts is challenging as a result of the uncertainty associated with new technology development, the need to bring together multidisciplinary expertise, and the multiplicity of actors and funding sources involved in promoting innovation.

From a policy perspective, there are typically multiple departments and agencies investing in potentially complementary areas. However, the ways in which individual efforts might be complementary are not always understood. Furthermore, opportunities to build on and complement private efforts also need to be explicitly identified and strategically exploited.

In this context, the international experience reveals increased emphasis on the need to ensure better coordination of government actors, technical expertise, and research and development infrastructure in order to promote innovation more effectively. Policies, programmes and institutions that facilitate close interaction and sharing of insights between laboratory-based researchers, manufacturing engineers, equipment manufacturers and user industries are receiving increased attention.

Another striking observation emerging from the international review is the creation of national frameworks of cooperation and communication. In Sweden, the **Swedish Governmental Agency for Innovation (VINNOVA)** recognises, as part of its mission to strengthen Sweden's innovation capacity and competitiveness, the critical importance of stimulating collaboration among the different actors of the innovation system, including companies, universities, colleges, research centres, the public sector and civil society.

VINNOVA activities cover a broad range of functions related to the coordination and formation of a common national vision around new technologies. The Agency's main instrument to ensure the coordination and alignment of efforts are the **Strategic Innovation programmes**, where actors involved in each field formulate a common vision and define needs and strategies for developing an innovation area, having as an overall goal the important societal challenges to create growth and strengthen Sweden's competitiveness. Strategic Innovation programmes cover the areas of mobility, the Internet of things (IoT), metal industries, medical technology and health care, manufacturing automation and digitalisation, and the sustainable use of resources.

National plans developed by multiple agencies responding to mandates at the highest levels of government can also play a role in bringing efforts together. The **US National Nanotechnology Initiative (NNI)**, for example, emphasises the importance of developing national strategic plans to create a consensus among multiple department agencies (many of which have sizeable budgets) working on similar technologies. These plans are developed every three years and, through them, high-level goals and priorities are identified and specific objectives of the participant organisations defined. The plans provide a framework under which individual agencies collaborate while pursuing their own mission-specific efforts. In particular, the NNI is expected to play an important role in creating a consensus among federal agencies on high-level goals and priorities in the specific field of nanotechnology, while providing clarity on how individual member activities contribute to such high-level goals and how their resources may leverage one another.

The international experience also reveals efforts to avoid duplication of investments and create critical mass. Many technological challenges require combined investments and efforts from multiple government agencies, and from the private sector. While public–private partnerships have been part of the policy discourse for many years, what is new is the attention given to ensuring that a variety of necessary investments take place at the required level. This includes ensuring that enabling elements such as fabrication methods and measurement tools are properly funded. It also includes ensuring that the community has access to a variety of demonstration and scale-up facilities (see next section).

For example, the NNI puts an emphasis on the important role that physical facilities can play as a space for collaboration. The NNI's approach is to incentivise multiple stakeholders to come together by making the available facilities equipped with the latest tools and served by well-trained staff.

Scale-up and "manufacturability" of emerging technologies

Ensuring that advances in technology made in a laboratory make their way into industrial applications is fraught with challenges. The path to successful commercialisation requires that technologies function well at large scale, and that the products are produced at industrial scale. For policy-makers, a central concern is the design of institutions, programmes and initiatives to ensure that research output is ultimately deployed in increasingly complex industrial systems, in order to enhance national competitiveness.

An underlying drive behind new policy efforts internationally in the area of scale-up is the need to ensure "value for money" when it comes to research and innovation. There is increased pressure from central governments and treasury departments to ensure that, in times of budget constraints, countries are able to capture value from their investments in science and innovation.

In this context, there is increasing recognition that technology scale-up requires the right combinations of tools and facilities. These include: advanced metrology, real-time monitoring technologies, characterisation, analysis and testing technologies, shared databases, and modelling and simulation tools. Also needed are demonstration facilities such as test beds, pilot lines and factory demonstrators that provide dedicated research environments with the right mix of tools and enabling technologies, and the technicians to operate them.[242]

The review of the international experience reveals that – with the aim of providing such tools, facilities and infrastructure – a number of countries are investing in applied technology centres and pilot production facilities focused on taking innovations out of the laboratories and into production. Examples of such investments include facilities within the **Manufacturing USA** institutes in the US, the **High Value Manufacturing Catapult Network** in the UK, and the **Pilot Lines for Key Enabling Technologies (KETs)** funded by the European Commission.

[242] O'Sullivan E., and López-Gómez C. (2017). "An international review of emerging manufacturing R&D priorities and policies for the next production revolution", in OECD (2017), *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris.

The **Manufacturing USA** institutes, for example, provide shared facilities to local start-ups and small manufacturers to help them scale up new technologies, accelerate technology transfer to the marketplace, and facilitate the adoption of innovation workforce skills. The institutes operate at regional level to take advantage of area-specific industrial clusters. However, the intention is to translate the institutes' technology and process learning to manufacturers throughout the country, and to bring together the institutes around common lessons learnt. A total of 1,174 organisations are involved, including SMEs and large multinational conglomerates, academia, not-for-profit organisations and federal agencies.

Inspired by the **Manufacturing USA** institutes, China has recently established its own **National Manufacturing Innovation Centres**, under the umbrella of the **Made in China 2025** initiative. The first of these centres, the National **Power Battery Innovation Centre (NPBIC)**, aims to accelerate the industrialisation of innovative battery technologies and enhance the competitiveness of China's power battery industry, not only through R&D, but also by providing testing services, pilot-scale experiments and industry support services. That is, the intention is to scale up to create a national industrial base around this technology area.

A key characteristic of the **Made in China 2025** innovation centres is their stated aim to help upgrade Chinese manufacturing industry from "Made in China" to "Designed in China". The focus is on capabilities for manufacturing scale-up, and on building a critical mass of multidisciplinary engineering R&D capabilities to accelerate the industrialisation of key cross-cutting industrial technologies. There is also a stated aim to build stronger linkages and alliances between universities, firms and public research institutes. Furthermore, the centres pay special consideration to local and regional contexts to achieve "differentiated development", supported by an active effort from national and regional authorities to ensure that private sector companies play a leading role in defining the centres' strategic direction.

The **Manufacturing USA** institutes and China's **National Manufacturing Innovation Centres** are just two examples of international efforts to bring together the right mix of research and innovation capabilities, facilities and partnerships required to translate research into industrial and economic impact.

SME capability-building

Many firms, in particular small and medium-sized enterprises (SMEs), are unable to exploit the opportunities offered by new technologies. Even when those technologies are readily available in the market, firms fail to take advantage of them to update their products and processes.

The case studies presented in the report suggest that the analysis of programmes and initiatives cannot be disconnected from institutional considerations. For building SME capabilities, there seems to be increasing recognition that decentralised facilities are necessary to be able to reach firms throughout the country. A key enabling factor for the **US Manufacturing Extension Partnership (MEP)**, for instance, is its network of nearly 600 offices and centres serving firms in all of the US states.

Another one is the range of other institutions, including universities, national laboratories and research centres, that the MEP is able to engage with. Examples of support provided to SMEs include product development and prototyping, technology-driven market intelligence and workforce development.

Another important observation is that building SME capabilities requires a range of support services. The international experience reveals that policy efforts range from "soft support" (such as the provision of information and support to create industrial networks around common interests) and "hard support" (hands-on support through activities such as training, contract research and expert advice).

The Singaporean experience with innovation and capability vouchers is an example of efforts to reduce the barriers that SMEs face to access expertise and technology. **Singapore's Innovation and Capability Voucher (ICV) programme** offers firms the possibility to access a range of consultancy services – from human resources and financial management to technical solutions. Some of the services are offered by local universities but also by the private sector.

The **ICV** is fully funded by the government, but its implementation relies on service providers, who are pre-qualified to ensure they deliver quality consultancy services. Universities and research centres are part of the list of pre-qualified service providers. The ICV scheme allows project follow-ups to incentivise SME commitment, while limiting the "over-use" of vouchers by the same companies.

In order to be able to deploy the different types of support demanded by client firms, a flexible institutional form might be required. This approach is exemplified by the **Singapore Institute of Manufacturing Technology (SIMTech)**. **SIMTech** provides a diversity of complementary innovation services to Singapore-based firms, including: support to develop R&D capabilities; collaborative R&D projects and consortia; supplier development programmes; and the provision of continuing education courses. Companies can also access the comprehensive array of diagnostic and measurement equipment housed at the institute. While **SIMTech's** mix of services caters for the more immediate needs of the industry, the institute still maintains significant research activities.

Another activity to support the technological upgrading of SMEs is the secondment of research scientists and research engineers to local firms through government-supported industry attachment programmes. Such exchanges of personnel help local enterprises identify critical technologies and build in-house R&D capabilities that are relevant to their operations. Furthermore, **SIMTech** also organises a number of seminars, workshops, fora and conferences as a way to communicate the latest advances in technology and generate awareness about their potential benefits. In some of these events, larger companies brief SMEs on current and future opportunities for local suppliers.

Finally, government-supported information dissemination mechanisms can play a key role in providing information about particular technologies, whose benefits have already been proven in the market place (e.g. quality management systems, energy-saving technologies, productivity-enhancing digital tools).

R&D collaborative networks

Not all firms have the capabilities to engage in R&D. A large proportion of firms do not have the time, capacity or funds to partner with universities or research organisations. The lack of engagement of firms in R&D and innovative activities represents a risk to long-term competitiveness in advanced industries that require continuous innovation.

The international experience reveals an increased emphasis on promoting collaboration among firms and institutions through R&D networks. This responds to a number of needs: engaging more firms in R&D, creating multidisciplinary teams, ensuring aligned investments in technology areas that depend upon one another and ensuring critical mass by bringing together financial resources.

All too often, progress in advancing the functionality of new application technologies and efforts to enhance the functionality of novel production technologies are carried out in isolation. However, advances in technologies may have an impact in different sectors and, as such, R&D networks can help to exploit opportunities for collaboration among sectors. Firms in aerospace and automotive, for instance, may have opportunities to collaborate in areas such as advanced materials and artificial intelligence, which are capturing an increased share of value added within those industries. Similarly, firms in those sectors might benefit from collaborations with sectors such as electronics and advanced machinery.

A prominent example of a large-scale national institution, with a focus on R&D networks, is Germany's Federation of **Industrial Research Associations (AiF**). Recognising the difficulty that firms, especially SMEs, face in engaging in R&D by themselves, AiF's "**Industrial Collective Research**" mechanism brings together groups of firms to identify their common needs with the support of experts from industrial research associations. In 2014 alone AiF disbursed around EUR 500 million in public funding.

The AiF case also represents an example of how non-governmental organisations can play an important role in bridging interests between industry and academia, facilitating the translation of knowledge and technology into commercialised solutions. The accountability of the Executive Committee to the General Assembly of AiF facilitates the articulation of the wide range of interests of their members to pursue common objectives, while preventing AiF from being captured by group interests. AiF's proven experience in working with local firms and the transparency in its organisation have motivated the government to appoint the association to coordinate and implement public funded programmes since the late 1970s.

Other initiatives that were analysed reveal the importance of industrial networks, involving SMEs and large firms, for identifying opportunity areas to be exploited, as well as areas where policy action might be required. Some of the programmes analysed are specifically focused on building stronger cooperation between small firms and large companies by funding collaborative projects. The **Central Innovation Programme for SMEs (ZIM)**, also in Germany, aims to support SMEs to develop new, or improve existing, products, processes or technical services. ZIM funds R&D projects, cooperation networks and the market launch of the results of the R&D projects.

R&D funding may be allocated to single projects, cooperative projects between SMEs (or SMEs and

RTOs), or funding of the management of innovative company networks and R&D projects generated by them – with a minimum requirement of six German SME partners. During the period 2015–17, 349 cooperation networks, 8,504 cooperation projects and 1,960 individual projects were supported.

Another dimension is participation in international R&D networks. As part of the **ZIM** programme, for example, agreements aimed at funding joint R&D projects between German and foreign firms have been established. One of these projects is based on a Brazil–Germany bilateral agreement (2017), through which ZIM finances the German partners involved, while the Brazilian organisations must secure funding through organisations such as **BNDES**, **EMBRAPII** and the State agencies supporting innovation.

Skills development in disruptive technologies

Skills are given central importance in national policy agendas around the world. Advances in new technologies require workers with new multidisciplinary competencies, combining different types of knowledge and skills. These trends impose challenges on both employees and employers.

SkillsFuture Singapore (SSG) is an example of a skills policy created in response to these emerging trends. **SSG** delivers a comprehensive strategy for skills development, including awareness-raising, mentoring and training on digital skills for different career stages. One of the key characteristics of **SSG** is its focus on people's careers, rather than solely on industry demands. Another relevant feature of **SSG's** strategy is the inclusion of ICT skills conversion courses. **SSG** has developed synergies with different actors and organisations across Singapore. These synergies show the importance of having agencies that work transversally on workforce development, such as **SkillsFuture Singapore** and **Workforce Singapore**.

SIMTech's case, on the other hand, shows a longer-term approach, based on R&D. **SIMTech** has collaborated with industry for more than two decades. The curricula of the courses delivered by the institute are industry-led and mainly specialised on precision engineering. The close relation between **SIMTech** and industry has allowed the institute to deliver highly practical courses.

The training programmes provided by the **National Institute for Bioprocessing Research and Training (NIBRT)** in Ireland are an interesting reference for Brazil, especially in sectors such as pharmaceuticals. Transnational corporations of the pharma sector operating in Brazil carry out limited R&D in the country, and one policy issue is how to motivate them to engage in R&D and innovation.

In this respect, the Irish **NIBRT** experience has grounded its skills development offering through collaboration with the industry. The **NIBRT** was funded as part of a broader strategy to attract foreign investment into the pharmaceutical sector. Its approach was to replicate state-of-the-art manufacturing facilities to provide the right environment for quality training. This effort is supported by the R&D activities performed within the institute, which include contract research. Moreover, the **NIBRT** has worked as an umbrella organisation, gathering in one place research and training expertise from different Irish institutions. The successful collaboration with the industry has allowed the **NIBRT** to maintain a strong track record of candidates obtaining employment in the pharmaceutical sector.

On the other hand, the **Competence Track for Automation and Digitalisation in SMEs (KOMP-AD)** in Denmark shows how vocational schools can deliver training on emerging technologies, adapted to the particular needs of SMEs. An evaluation of the programme has provided evidence of a positive impact, especially on productivity at company level. The evaluation found a large amount of unexplored potential for increasing the digitalisation and automation levels of Danish SMEs. Approximately half of the participating companies indicated that they would not have taken part in any competence development course had they not had the opportunity to join **KOMP-AD.**

Cross-cutting observations

The report highlights increasing recognition internationally that the ability of nations to translate new technologies into high-value production within their economies depends on how the science and engineering base are integrated in the domestic industrial system. A weak connection between science and industry could constrain the potential of new technologies and the economy's ability to innovate the next generation of high-value products.

To compete effectively, therefore, national economies require industrial systems that can respond to emerging high-value industrial opportunities with the right combinations and clusters of technological R&D, skills, institutions and infrastructure.

Policies addressing the scale-up of novel technologies may involve a set of solutions focusing on R&D-based solutions and novel tools, production technologies and facilities to develop, test and demonstrate emerging applications, as well as to bridge innovations from laboratories to production, thereby increasing "the scale, speed and scope of commercialisation".

Countries with greater research capabilities in various areas of knowledge, with greater collaboration within and across borders, better functioning institutions, a vast pool of educated citizens, mobility of skilled labour, public–private investments focused on the complementarity of intangible capital, and forward-looking policies are likely to enjoy continuing industrial competitive advantage.

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