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Innovation support in the enterprise sector: Industry and SMEs

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ABSTRACT

This Policy Paper outlines major policy trends in the support of innovation activities in industry and SMEs across OECD countries. It discusses the policy mix to strengthen business R&D and innovation, and discusses possible avenues to improve this policy mix in response to evolving needs, partly driven new trends in technology. Across the OECD, governments strive to reinforce international competitiveness through a variety of policy initiatives supporting business innovation. In particular, these initiatives facilitate the technological upgrading of existing industries and facilitate the development of strategic sectors, stimulate investment in the development and uptake of new technologies, and the upscaling of SMEs and start-ups that play a central role in rejuvenating and strengthening the economy but face specific obstacles to engage in R&D. Twelve case studies discuss selected initiatives in the following areas: Support for innovative enterprises and clusters, development of strategic industrial sectors in manufacturing in particular, and the transition of industry towards new methods of production (Industry 4.0). The dimensions critical for the effective implementation of these initiatives vary according to the nature and purpose of the initiatives. However, this Paper identifies some features and properties that may help identify good practices in their design, implementation and evaluation.

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Executive summary

OECD countries have a long history of supporting business innovation. During and after World War II, technologically advanced countries' policies centred on "missions" which were often related to defence and security, focusing on large-scale technologies and systems (including in the nuclear, aerospace, and transport sectors, and wider energy areas). This included dual-use and other "strategic sectors. The need for structural adjustment in response to the recession of the 1970s triggered a wave of "defensive" industrial policy, intended to rescue ailing industries. With the demise of the "defensive" approach, science, technology and innovation (STI) policy gradually emerged as the core of a new industrial policy, aimed at modernisation and strengthening industry competitiveness (in the late 1980s and 1990s). Support for key enabling technologies, such as microelectronics, biotechnology and new materials was a critical element of this policy.

During the era of accelerated globalisation in the 1990s, industrial policy became more "horizontally" oriented, focusing on business-friendly framework conditions and generic public support for innovation, without abandoning the sectoral dimension altogether. The use of direct public support became more strictly regulated. However, support for industrial research and development (R&D) has generally been less tightly constrained than subsidies for other purposes. Policy also focused increasingly on small and medium-sized enterprises (SMEs) and innovative start-up firms and their capability for upscaling.

Still in the 1990s, the national innovation systems approach, emphasising combined analyses of the generation, diffusion and use of knowledge, gained steam as a reference for innovation policy. In this systems context, the quality of interactions between the science and business sectors and among firms became a priority policy issue. Today, a systemic perspective is also applied in the discussion on "transformative policies" that seek to tackle and shape large-scale transformations driven by technological and societal change, and grand societal challenges. The emergence of a new "mission-oriented" approach in STI is taking place in this wider policy context.

This Policy Paper gives the conclusions of twelve case studies of initiatives in the areas of i) support for innovative enterprises, including innovation clusters; ii) the development of strategic industrial sectors, particularly for the manufacturing sector; and iii) the transition towards new methods of production – Industry 4.0. These initiatives contain a number of shared features suggesting good practices.

i) Support for innovative enterprises, including innovation clusters

- **Evaluation**: To ensure the impact of policy initiatives, monitoring and evaluation have become an integral part of many support initiatives.
- **Stability and predictability of public support**, offering a margin of adjustment to respond to temporary (in times of recession) and adaptation (to emerging new needs) contribute to the success of support initiatives.
- **Targeting support to specific needs of firm:** Some initiatives related to start-ups focus on their specific needs and take account of the entire funding cycle. Access to specialised technical expertise and research infrastructure for start-ups and SMEs facilitate the transformation of new concepts into new products and services.
- **Supporting innovative SMEs through public procurement:** Public procurement is leveraged by aligning governments' strategic needs and the development of expertise

and capabilities in specialised start-ups and SMEs and by supporting the commercialisation of innovative products and services.

ii) Development of strategic industrial sectors, particularly in manufacturing

- **Collaboration between industry and science:** Initiatives supporting joint research between businesses and research institutes plays an important role for the transformation of existing industries and in supporting emerging sectors.
- **Developing regional clusters:** Building public-private partnerships involving co-operative research consortia between academia and industry, help establish technically competitive research infrastructure.
- **Combining the expertise and potential of different types of firms:** Linking the expertise and capacities of large multinational enterprises with the creativity of SMEs and start-ups is an emerging feature of some new initiatives that harness complementary capabilities and reduce financial risks to participating firms.

iii) Transition towards new methods of production – Industry 4.0

- **Development of skills and competences:** New initiatives supporting transition tend to emphasise both R&D (for new technologies and production processes) and the complementary development of the skills and competencies of the workforce.
- **Engaging stakeholders through platforms and networks:** Involving public and private actors in the identification of challenges has been helpful in aligning research and the evolving needs of industry.
- **Diffusion of new technologies:** Institutions for the diffusion of new technologies play a central role in the transition towards new production methods relevant to Industry 4.0. Some successful initiatives build on existing networks and encourage stakeholders (universities, intermediaries, private organisations) to pool resources.
- **Evaluation of diffusion institutions and initiatives:** The needed evaluations requires the application of new evaluation metrics, taking due account of the features of new production processes and their systemic properties.

1. Introduction

1.1. Rationales and instruments for innovation support to the business sector

OECD countries have a long history of supporting innovation in the business enterprise sector (Ergas, 1986; Freeman and Soete, 1997). Emerging economies have followed suit in several waves of catching up. During or immediately after World War II, some technologically advanced countries' policies centred on "missions". These were often related to defence and security, focusing on large-scale technologies and systems (including in the nuclear, aerospace, and transport sectors, and wider energy areas). This approach included dual-use and other "strategic sectors", extended to enabling technologies. In France, industrial policy was strongly sector-based, implemented through so-called "grand projects" that would exert considerable impact on the country's specialisation patterns (Cohen, 2007). Across the industrialised world, structural adjustment as a response to the recession of the 1970s triggered a wave of essentially "defensive" industrial policy measures, intended to prop up and consolidate ailing industries. However, this type of policy became increasingly untenable as structural problems lingered.

With the gradual shift away from this type of policy response, science, technology and innovation (STI) policy emerged as the core of a new industrial policy aimed at modernising and strengthening industry competitiveness in the late 1980s and 1990s (Soete, 2007). Support for key enabling technologies, such as microelectronics, biotechnology and new materials, which were considered relevant to a wide range of industries, was a critical element of this policy shift. Academic work on "strategic industries" by trade economists such as Paul Krugman drew additional interest to the issue of international competition in high-technology industries (exemplified at the time by the Airbus-Boeing contest, and related industrial and trade policy measures).

During the era of accelerated globalisation in the 1990s (and the creation of the "single market" as a pillar of the European Union's ambitious integration project), industrial policy became more "horizontally" oriented, focusing on business-friendly framework conditions and generic public support for innovation, without abandoning the sectoral dimension altogether. The use of direct public support became more strictly regulated, although support for industrial research and development (R&D) has generally been less tightly constrained – and graded according to its distance to the market – than subsidies for other purposes. Policy also focused increasingly on small and medium-sized enterprises (SMEs), whose specific needs have become more prominent as a policy focus over time, recognising that these firms face particular obstacles to innovation. Moreover, innovative start-up firms and their capability for upscaling have played an important role in rejuvenating the economy in recent history. Still in the 1990s, the national innovation systems approach, emphasising functional aspects in the generation, diffusion and use of knowledge, gained steam as a reference for innovation policy. In this context, the transfer of knowledge and new technologies between the science and business sectors became a policy priority.

Today, the policy discussion on "transformative policies" addressing large-scale transformations seeks to respond to technological and societal change, as well as tackle grand societal challenges. The ongoing debate on a new "mission-oriented" approach in STI is taking place in this wider context policy (Mazzucato, 2018).

Dedicated innovation policies designed to have a *direct* impact on business innovation performance are one important way in which governments employ a wide range of policy instruments to enhance – and to some extent shape – business R&D and innovation activity.

Together, they make up a comprehensive "policy mix" (OECD, 2010) that fulfils several functions, including:

- **Providing incentives for firms to invest in generating new knowledge and the technology required for innovation:** policy instruments in support of R&D include grants, loans and equity, as well as tax incentives for R&D. In recent years, new – and sometimes comprehensive – approaches have been developed to address sector-specific challenges by reinforcing and aligning research and innovation activities across various actors, both within and across sectors.
- **Stimulating the uptake of new technologies and new ways of doing business:** this is achieved through a set of financial and non-financial instruments, including awareness programmes, information and demonstration initiatives, and various kinds of infrastructure support. Demand-side measures, such as public procurement, also play an important role.
- **Encouraging the transformation of existing industries and the development of strategic industries:** this is done, for example, by promoting new paths of technology development and new business models.

Other policies impact in *indirect* (but nevertheless highly significant) ways on business innovation performance. Business innovation activity critically depends on governments providing framework conditions that are conducive to innovation and entrepreneurship. These include competition frameworks driving innovation; innovation-friendly tax rules and regulatory frameworks in product and labour markets; favourable international trade and investment regimes; access to critical infrastructure and resources (e.g. human, financial and information-related), which may constrain some innovation actors more than others; and an effective intellectual property rights system that strikes a balance in dealing with the trade-offs typically involved in such a system. A country's education and skill-development capacity, as well as the ability of its higher education institutions and public and private research institutes to attract world-class talent, have become key factors in its innovation performance (e.g. OECD, 2018a). The most innovative countries tend to have favourable framework conditions, as well as high-performing (public) research and higher education institutions, although the level of public support to businesses varies widely. In some cases, dedicated innovation policy interventions are employed to compensate for shortcomings in general framework conditions (OECD, 2014a). Recent approaches to industrial policy highlight the dependence of innovation on high- quality framework conditions (Aghion, Boulanger and Cohen, 2014; Warwick, 2013). They explore practical ways – including through institutional innovations – to make them more conducive to innovation (Rodrik, 2004, 2007, 2008), highlighting the role of information, data access and government capacity (Maloney and Nayyar, 2018).

Many OECD countries are intent on improving the policy mix for business innovation at a system level. Most governments today operate a large number of programmes and instruments supporting R&D and innovation in the business enterprise sector. Individual instruments can yield more – and improved – results if they are better co-ordinated and interlinked. A critical element in this regard is co-ordinating individual programmes and schemes through better governance, e.g. assigning dedicated agencies to operate sets of related instruments (see Monograph 6 on governance). For countries offering tax incentives for R&D and innovation, the adequate design of these fiscal instruments, as well as their interaction with direct public support programmes and instruments, is another key area for policy attention. Section 2 discusses these two aspects of policy co-ordination in more detail.

1.2. Structure of this monograph

This monograph presents the conclusions from 12 case studies in three policy areas: i) support for innovative enterprises, including innovation clusters and technology parks; ii) development of strategic industrial sectors, particularly for the manufacturing sector; and iii) the transition towards new methods of production – Industry 4.0. Table 1 shows the selected case studies, representing initiatives in comparator countries. Section 2-4 summarises key issues and conclusions for each of the three policy areas, referencing the case studies. The detailed case studies are available online (OECD, 2019).

Table 1. Selected case studies, by country and type of policy initiative

	Support for innovative enterprises, including innovation clusters and technology parks	Development of strategic industrial sectors, particularly for the manufacturing sector	Transition towards new methods of production – Industry 4.0
Austria		• Virtual Vehicle R&D centre (COMET)	
Denmark			• Manufacturing Academy of Denmark (MADE)
Germany	• Central Innovation Programme for SMEs (ZIM) • High-tech Start-up Fund (HTGF)		• Industry 4.0* • SME (Mittelstand) 4.0
Israel		• Innovation Labs programme	
Sweden			• Produktion2030 (one of the strategic innovation programmes)
United Kingdom	• High-Value Manufacturing Catapult Centre (HVMC)		
United States	• Small Business Innovation Research (SBIR) programme	• Manufacturing USA • New York Nanotechnology Cluster	

2. Support for innovative enterprises, including innovation clusters and technology parks

2.1. Policy challenges and trends

Supporting innovation in business enterprises, including SMEs, has been a policy priority in OECD countries for several decades. The emphasis on SMEs is based on the insight that such enterprises face specific obstacles when engaging in R&D and innovation, many of which can be traced back to market failures. As a result, most governments in the OECD area operate a large number of programmes supporting R&D and innovation in firms. They have also developed programmes and policy instruments that seek to improve innovation outcomes by specifically supporting R&D collaboration, and knowledge and technology transfer – or, in a multidirectional and more interactive perspective, co-creation involving actors from other parts of the innovation system, such as universities and public research institutes (see also Monograph 3 on policy initiatives for the commercialisation of public research). Given the scope and volume of existing public support for R&D and innovation, and the business sector's evolving needs in response to global competition and technological change, the focus of policies has been shifting. The governments of the countries analysed in this monograph emphasise the following policy issues and areas:

- **Designing a coherent mix of tax and direct support instruments for R&D:** if designed adequately, tax incentives are an effective instrument to stimulate more R&D investment, including in SMEs that are already actively performing R&D (Larédo et al., 2016). By contrast, grants might best be used to support riskier projects or scale up certain activities, including start-ups and young firms with growth potential. Loans may be useful to facilitate diffusion-oriented R&D (which requires a combination of new-technology development and capital expenditure), and under specific macroeconomic and financial conditions. Over time, a discernible shift has taken place across countries towards tax incentives for R&D. Some countries (including France) rely rather heavily on this type of support, and others (such as the Netherlands) almost entirely (OECD, 2018b).
- **Increasing the effectiveness and efficiency of programmes and public support instruments for business R&D and innovation:** based on more – and more rigorous – evaluations of policy initiatives, governments seek to redesign policies to achieve better results for the money invested. This could involve individual initiatives, or better management of a portfolio of related programmes and instruments. Policy evaluations indicate that individual instruments could yield more and better results if they were better co-ordinated and linked to each other. Designing a more effective policy mix means better targeting instruments towards the specific needs of different types of firms and leveraging the interactions between individual instruments. This can be achieved, for instance, by designing integrated programmes or sequencing of funding instruments (see the case study of the German ZIM programme (OECD, 2019)). Simplifying access to funding schemes and increasing transparency by establishing one-stop-shops or digital support services are other important elements that contribute to an improved innovation policy mix (e.g. Innovation Fund Denmark).
- **Realising the benefits of open innovation:** innovation policy has a long track record of stimulating collaboration among various actors of the innovation system, and precedes the "open innovation" terminology widely used in recent years. In recent decades, new

forms of interaction beyond collaboration on R&D projects have also been emphasised, e.g. collaboration within clusters, networks and other organisational structures that enhance knowledge exchange among firms, universities and research organisations; and collaboration between developers and users of innovations (e.g. Japan's Industrial Cluster Policy). In addition, new types of co-operative infrastructures have been established, including innovation labs, innovation campuses and joint research facilities combining science and industry. This is exemplified by the Austrian COMET centres – a type of institutionalised public-private partnerships commonly referred to as "competence centres", which has spread across OECD countries since the late 1980s – and the German Research Campus initiative. A further area of policy promoting open innovation focuses on improving access to data and scientific results through open-data and open-science initiatives. A related policy priority is fostering the exchange of researchers between industry and science, e.g. through industrial PhD and post-doc programmes. One example is Innovation Fund Denmark, established in 2014 to combine research, technology development and innovation support, and discussed below in the context of MADE.

- **Strengthening high-tech SMEs and young firms with scale-up potential**: governments have progressively come to recognise entrepreneurship as a major driver of innovation, productivity growth and job creation. Innovative start-ups bring new ideas to the market, sometimes tapping into knowledge generated but not commercialised by existing firms. As important economic impacts are usually limited to fast-growing (and often young) firms, policy interventions increasingly address scale-up firms and high-tech SMEs that promise to make a difference to the innovation system at large. Policy priorities in this area include venture-capital programmes that supply these firms with equity to grow (see the case study on the German High-tech Start-up Fund (OECD, 2019)). Other types of assets they need are technologies and infrastructure, including incubators and technology centres (see the case study on Israel's recently established Innovation Labs programme (OECD, 2019)). In addition, start-ups emerging from universities and public research institutes, increasingly involving students as founding actors. Providing "funding packages" that match the needs of high-tech start-ups has become a specific concern, meaning that instruments should be designed along funding cycles, from the pre-seed phase through start-up and expansion. They should combine grants and equity instruments, and involve private investors.
- **Supporting clusters** can help reduce R&D and other (e.g. transaction) costs, and help introduce innovations to the market by linking users and producers. To avoid lock-in, however, clusters should be open to partners outside of a predefined cluster region. Instead cluster themes should be developed in bottom-up, dynamic way, with due consideration given to cross-sectoral and cross-technology activities. In general, governments should engage with existing or emerging clusters, rather than attempt to create them from scratch (Warwick and Nolan, 2014; OECD, 2013). Technology parks and incubators support clustering of innovative firms. Rather than being viewed as stand-alone instruments, they should be seen as complementing other initiatives and programmes. Swann (2009) reviews the advantages and disadvantages of clusters.

This monograph covers four initiatives supporting innovative enterprises: ZIM and the High-tech Start-up Fund (HTGF) in Germany, HVMC in the United Kingdom and the SBIR programme in the United States (Table 2).

Table 2. Support for innovative enterprises, including innovation clusters and technology parks: Overview of case studies

Policy initiative	Country	Period	Annual budget (million)	Brief description
ZIM	Germany	2008-present	555	The single-largest grant programme supporting the R&D activity of SMEs in Germany. ZIM provides grants covering 25-55% of R&D costs (up to EUR 380 000 for SMEs, and up to EUR 190 000 for universities and research organisations).
HTGF	Germany	2005-present	> 50, of which 30% is financed by business enterprises	Initiative to close the gap in seed financing for high-tech start-ups in Germany. The funding volume includes over 30% from private investors, covering established SMEs and large companies. In the first round, the fund invests up to EUR 500 000 in a firm; in a potential 2nd round, the fund can provide up to EUR 1.5 million in additional equity capital.
HVMC	United Kingdom	2011-present	> 300 (> 800 for the entire Catapult Centre Programme), 30% of funding through commercial R&D contracts	A network of seven collaborative public-private R&D institutes aiming to improve the competitiveness of the UK manufacturing sector by focusing on commercialising new manufacturing technologies. A three-pillar funding model, combing institutional public funding, collaborative R&D project grants and commercially funded R&D contracts, strikes a balance between risk-taking, collaboration and stimulation of innovation.
SBIR programme	United States	1982-present	> 2 300	Long-standing programme to engage SMEs in federally funded R&D and increase private-sector commercialisation of innovation derived from such funding. The SBIR programme provides three-phase funding: Phase I: USD 150 000 for a feasibility study; Phase II: up to USD 1 million for performing R&D; Phase III: commercialisation through follow-on R&D funding from the mainstream budgets of government agencies (not involving SBIR funding).

Notes: Annual budget corresponds to the most recent data available from official programme websites.

2.2. Monitoring and evaluation strategies

Monitoring and evaluation have become standard features of support programmes for business R&D and innovation. However, practices differ depending on the objectives, types of programmes and countries. While ex-ante or ex-post programme evaluations have become common, they often face conceptual challenges or are limited in scope:

- The evidence on direct support for business R&D through grants, loans and loan targeting the most salient activities and actors for meeting public policy goals often focuses on input additionality (notably measuring the extent of additional business spending on R&D stemming from the support). Less attention has been devoted to the effects on output, e.g. in terms of innovation, employment and productivity (Warwick and Nolan, 2014). Few evaluations link a programme's effectiveness to cost-benefit analyses (Lokshin and Mohnen, 2012).
- Innovation-oriented procurement programmes are generally under-evaluated compared to other categories of innovation support. This is at least partly a reflection of the technical challenges of such evaluations and the relative novelty of demand-side policy. A notable exception is the US SBIR programme, which has generated the most significant evaluation effort in the area of pre-commercial procurement. More generally, the data used to evaluate innovation-oriented procurement programmes are often inadequate for assessing innovation impacts. Little consideration has often been granted to how this instrument might best be assessed. "Overall, the evidence base on the efficacy of innovation-oriented procurement is weak, and often based on self-reports,

rather than attempts to quantitatively assess a counterfactual" (Warwick and Nolan, 2014).

- Evaluations of policy instruments that address financing gaps and correct perceived market failures by supporting risk capital, and in particular seed and early-stage finance, are relatively recent. However, the effects of equity programmes may take many years to materialise – in any event, longer than typical grant or loan-guarantee programmes. The lack of available data and appropriate control groups for evaluations is inherently more problematic in the new and emerging industries to which these schemes tend to be applied (Warwick and Nolan, 2014). In addition, impact assessments that rely on individual firm-level data face access restrictions (Livraga, 2018).
- Conducting robust evaluations of cluster initiatives is difficult, as much of the available information is based on self-reports by the targeted firms. Selecting the appropriate evaluation criteria and indicators is a challenge when evaluating the effectiveness of cluster-support policies (Technopolis and MIoIR, 2012). Cluster evaluation can also follow different approaches, focusing either on the benefits to firms of cluster membership, or the rationale for and effects of government policy. The different types of intervention involved in policy support for enterprise clusters further complicates their evaluation (Technopolis and MIoIR, 2012; Warwick and Nolan, 2014).

Despite these challenges – and partly owing to tighter constraints on public budgets – monitoring and evaluation generally become integral components of initiatives and programmes supporting innovation. In many cases, they are performed by an independent organisation. In Germany, an independent organisation (the RKW Kompetenzzentrum) monitors the ZIM programme on an ongoing basis, and publishes analytical reports based on data from the programme agencies and beneficiary surveys. The ZIM programme has also undergone an impact evaluation of its effectiveness and efficiency, and a larger impact evaluation of the funding activities was launched in 2018 (the final report is expected to be completed by the end of 2019). Monitoring of the HTGF is carried out by independent institutions and comprises an ex-post performance assessment of each financial period. The monitoring aims to obtain empirical information about the performance of the HTGF against its objectives and improve the fund's operation where necessary. The most recent evaluation of the HTGF was based on a literature review, interviews with selected companies receiving HTGF funding, analysis of the documents and contact database of the HTGF, and an online survey of start-up entrepreneurs.

In the United Kingdom, a specific effort has been made to evaluate the Catapult centres. The largest among them, the HVMC – itself a network of seven centres – was subject to an impact assessment in 2015, primarily based on interviews of participants in the HVMC. A new evaluation framework, including high-level objectives and customised logic models for each of the 11 Catapult centres, was published in 2017. A retrospective evaluation by Innovate UK was conducted in 2018, in collaboration with industrial stakeholders. This evaluation assessed the impact of HVMC activities from its inception in 2011 to the middle of 2016, based on a logic model across three strands (activities, output and outcome). The evaluation drew on case studies, firm surveys, consultations with academia and policy makers, and analysis of HVMC data. The evaluation further articulates the economic benefits of the HVMC in terms of its impact on industry and competence development.

In the United States, evaluation and monitoring for the SBIR programme have been provided through an independent third party, the Science, Technology and Economic Policy Board of the National Research Council (NRC) at the National Academy of Sciences. A comprehensive evaluation of the SBIR programme was carried out in 2014/15, comprising three phases. The first phase focused on developing an evaluation framework (which was reviewed by an independent panel of experts) and gathering information. The second phase involved multiple surveys and case studies of a wide range of SBIR-awarded firms. The third phase explored additional issues that emerged during the evaluation. A number of quantitative evaluations of SBIR carried out prior to 2010 aimed to identify business-generated revenues linked to the programme. In addition to the overall programme evaluation, individual assessments of the SBIR programmes of the participating government agencies are conducted regularly.

2.3. Critical dimensions

The dimensions deemed critical to implementing a public support programme, and hence determining its success or failure, differ according to the type and nature of the programme. For "basic programmes" that aim to provide generic support for R&D (notably for SMEs), the critical dimensions are low barriers to access, flexibility in application procedures, low transaction and compliance costs, and the provision of useful client-oriented consultancy services by the agencies in charge of delivering the programme.

A dimension that has contributed to the successful implementation of Germany's ZIM has been its stability over time, combined with regular adjustments at the margin (e.g. subsidy rates by type of firm and type of project). This feature provides firms with the necessary degree of certainty about the actual funding levels they receive, which helps them plan their R&D activities. Other success factors – from the perspective of the funded firms – include the absence of fixed, pre-defined deadlines for grant applications, the openness of the programme to all fields of technology and thematic areas, freedom in the choice of project partners, a low level of red tape and competent support by the programme administration. In addition, success rates in the ZIM programme have been relatively high for an extended period of time, which results in a high ratio of total grants to application costs compared to other R&D programmes in Germany. A recent success factor of the ZIM programme is the increased transparency about the available funding opportunities and a more coherent support system (which resulted from a merger of various schemes).

A critical dimension of the German HTGF is its performance as a "market maker" and as an institution performing quality screening among potential investment targets, which seems to have led to substantial crowding in of private investment. By reducing investment risks while contributing to the growth of the financed start-ups, HTGF activities also allowed private VC companies to invest jointly in promising enterprises at a later stage. The fund has sustainably stimulated the market's seed financing with over 500 investments. In total, more than EUR 1.5 billion – mainly in private capital – has been mobilised for follow-up financing. The offers for early-stage financing have substantially increased thanks to the growth in business angels, as well as the emergence of new co-operation and financing models such as incubators and accelerators.

The HVMC in the United Kingdom provides industrially scalable technology, making it a critical asset in support of the UK manufacturing industry. A critical dimension of its success are the 2 000 engineers and scientists working at the HVMC centres, whose capability and critical mass allow them to develop expertise in advanced manufacturing technologies. Another factor appears to be the three-pillar funding model, which helps maintain a balance between risk-taking, collaboration and stimulating innovation.

A number of dimensions contribute to the success of the SBIR programme in the United States in enabling SMEs to develop technical innovations. One success factor is the SBIR awards' role in certifying firms' quality. The programme's combination of public R&D support with ex-ante screening of potential ventures helps ease financial constraints by certifying venture quality to potential financiers. This helps firms attract additional angel and VC investments in their R&D, adding to the programme's success. Thus, SBIR can be viewed as a seed fund, significantly reducing the risks to private-equity providers for follow-on financing and product commercialisation. The focus on SBIR on high-risk R&D effectively encourages novel research and plays a catalytic role at an early stage in the technological development cycle. In addition, SBIR provides a bridge between university research and the marketplace, supporting the commercialisation of academic research. The programme's flexibility helps meet the multiple mission requirements of the respective government agencies. For entrepreneurs, having the government as a customer provides a critical source of early cash flow for early-stage ventures. The SBIR programme gives successful firms a "single-source" contract for the subsequent development of technologies and products derived from the SBIR award. This often helps small firms take an alternative path to enter the government procurement system.

2.4. Conclusions

In Germany, the ZIM programme improves access to funding by providing basic support for R&D and innovation in SMEs. A salient feature of the ZIM programme is its stability over an extended period of time, which helps stabilise the expectations of SMEs active in innovation. While maintaining stability, the programme has responded to exceptional situations, such as the sharp recession of 2009, and has from time to time been adjusted at the margin to reflect emerging new needs. The programme's design and management contribute to low access barriers – including by setting no fixed deadlines for applications, as well as low transaction and compliance costs – and provides customised solutions for SMEs. The HTGF extends seed and early-stage financing to mitigate existing financing challenges facing high-tech founders. Through these "funding packages", which combine grants and equity instruments and involve private investors, correspond to the needs of high-tech start-ups over the entire funding cycle (from the pre-seed to the start-up and expansion phase), the HTGF has attempted to optimise the effectiveness of its instrument mix. In the United Kingdom, the HVMC centres provide specialised technical expertise, equipment and other resources that are not readily available to firms, in particular SMEs, but are needed to transform concepts into new products and services. Israel's Innovation Labs combine the expertise of specialised firms with the innovative potential of start-ups, supporting collaborative innovation activities that help participating firms overcome specific gaps, e.g. in access to research infrastructure, expertise and new knowledge. In so doing, the programme mitigates the risk of pursuing innovation activities and reinforces the growth of potentially promising industries in Israel. In the United States, the SBIR programme supports technological innovation by investing federal research funds in priority areas deemed critical for the United States and encouraging small businesses to commercialise innovation derived from federal R&D funding. SBIR also provides government agencies with new, cost-effective solutions to meet specific needs. Looking back over its long history, the SBIR programme has succeeded in selecting some enterprises with the highest stock-market capitalisation in the world.

Several of the policy initiatives and programmes discussed in this monograph stand out by their new and innovative approaches to supporting innovation in firms. For instance, the US SBIR programme and Israel's Innovation Labs programme (discussed in Section 3) are useful additions to the national policy mix for business innovation. The objective of SBIR to meet strategic the needs of government agencies while mobilising innovation in SMEs makes it a milestone programme in public procurement, which as inspired similar programmes in several other OECD countries, even though it has been in place for a long time.

3. Development of strategic industrial sectors, particularly for the manufacturing sector

3.1. Policy challenges and trends

The sectors that are considered "strategic" have changed over time. In the post-WWII reconstruction period, steel and other "basic" sectors were considered of high strategic importance; the same holds true for consecutive cohorts of emerging economies, e.g. in East Asia (Yusuf and Nabeshima, 2009). In advanced economies (and some large emerging economies capable of mobilising the necessary resources), strategic areas such as defence, energy and transport were developed through related "missions", e.g. involving aerospace and nuclear technology (Arundel and Soete, 1993; Kuittinen, Polt and Weber, 2018). In many countries, the focus shifted in the 1980s from sector-oriented policies towards those promoting new enabling technologies, e.g. microelectronics. With globalisation and fragmentation of value chains picking up speed in the 1990s, manufacturing in OECD countries has been challenged by new competition from fast-growing emerging economies. One response to this challenge has been to transform manufacturing activity by moving further along value chains, integrating customer sectors, and exploring new opportunities to increase and capture value added through servitisation.

In recent years, transformative change and societal challenges have been moving up on policy makers' agendas. Deep and pervasive transformations, such as digitalisation, are not confined to particular sectors and industries (although they may affect them in different ways and levels of intensity). Grand societal challenges and transitions also require integrated, cross-sectoral innovation policies. Major ingredients of related programmes are cross-sectoral co-operation, and the involvement of existing firms, start-ups and new industrial and societal actors in a greater variety of policy areas.

These challenges have several implications for policy, including:

- **Transforming existing ("traditional") industrial sectors and seizing new industrial opportunities.** This often entails both strengthening existing sectors (which currently enjoy comparative advantages, although these may be eroding or face threats in the future) and enabling them to tackle new developments (e.g. the transition of the automotive sector towards new forms of mobility) and create or enter new markets. Typically, this requires high-profile strategies involving all relevant industry and government actors from a variety of ministries and agencies (sometimes at both the national and regional levels), as well as research actors; developing a long-term, systemic view of sector development (e.g. through the use of foresight instruments); and preparing a flexible response to changes in the environment (Wessner and Howell, 2018). The "Top Sectors" policy in the Netherlands took a more bottom-up approach to sectoral development. This approach relies strongly on actors' self-organisation and shaping the framework conditions, notably by aligning the research agendas of industry and knowledge institutions, with less focus on the direct provision of subsidies (OECD, 2014b; Arnold et al., 2018). It has been the predominant industrial and innovation policy approach in the Netherlands for nearly a decade, and has recently entered an adaptation phase.
- **Broadening the application of new key enabling technologies** and new impulses from "outside technologies" (i.e. which have so far not been at the core of technology development in the sector). Today, this often means resorting to digitalisation, linking

manufacturing concepts with servitisation approaches (which are also often linked to digitalisation). One example of trans-sectoral developments are new mobility solutions that link new vehicle technologies to new ways of organising mobility needs, like Germany's National Platform Future of Mobility). Another response is developing new business models for manufacturing. Supporting firms (specifically SMEs) in developing new business models based on smart services is one such approach, as evidenced by the Danish Remodel programme.

- **Using the potential of technological change for radical innovation.** The competitiveness of manufacturing in OECD countries is highly dependent on firms' ability to advance and benefit from critical technologies that open up radically new paths of innovation. Among other technology areas, nanotechnology, photonics, new materials and microelectronics are key enablers of technological innovations (see, for example, Monograph 5 on health and biotechnologies). Since technological development in these fields is strongly science-driven, close co-operation between industry and science is paramount. While government policies tend to focus on funding R&D, they also promote regional clusters (like the New York Nanotechnology Cluster in the United States).
- **Linking innovation support to grand societal challenges.** Innovation in the business sector is a critical element of any effective response to the grand societal challenges facing industrial societies today, including climate change, natural-resource scarcity, population ageing and security. Thus, linking innovation support to these challenges has become a key feature of innovation policy in most OECD countries. One approach is to develop technologies that help tackle these challenges and can be implemented through "mission-oriented" approaches (Mazzucato, 2018). Innovation support can be linked more directly to new demand and requirements deriving from grand societal challenges. For transformative policies to be effective, supply and demand-side instruments and changes in the regulatory framework have to go hand in hand (see also Monograph 2 on sustainable development.) It has become increasingly evident that transformative policies also entail innovations in the design and implementation of research and innovation programmes. Tackling these challenges requires interdisciplinary and intersectoral approaches. Sweden (notably through its innovation agency Vinnova) and other Nordic countries, such as Finland and Denmark, have also been playing important roles in exploring and experimenting this policy area (OECD, 2017b, 2017c).

This monograph covers four initiatives aiming to develop strategic industrial sectors: Austria's Virtual Vehicle COMET centre, Israel's Innovation Labs programme, and Manufacturing USA and the New York Nanotechnology Cluster in the United States (Table 3).

Table 3. Development of strategic industrial sectors, particularly manufacturing: Overview of policy examples

Policy initiative	Country	Period	Annual budget	Brief description
Virtual Vehicle COMET centre	Austria	2008-present	EUR 12.2 *) (>100 for the entire COMET programme); 50% financing from business enterprises	Competence centre for collaborative research of research institutions and industry partners, with technology transfer and related training in new and promising fields of technology in the automotive and rail sectors that involve high-risk research activities.
Innovation Labs programme	Israel	2018-present	n/a	Incentive programme enabling open innovation processes promoting the growth of companies through innovation labs while assisting start-up firms in accessing advanced means of production, R&D capacities and access to sales channels. Specialised firms – Israeli or foreign-owned – with proven expertise in specific fields that add to the Israeli economy's development potential may receive EUR 1 million to set up an innovation lab and EUR 120 000 per year towards the operational costs for a maximum of six years. Start-ups under an innovation lab may receive public funding of EUR 200 000 from the Israel Innovation Authority.
Manufacturing USA	United States	2011-present		A network of research institutes supporting innovation in advanced manufacturing through co-financed and collaborative research between industry, universities and government.
New York Nanotech Cluster	United States	2001-present	USD 420 million, including substantial private firm funding through PPPs. Between 2001 and 2013, private-sector firms contributed about 60% of the PPPs	Transformation of the New York upstate region into a leading centre of nanotechnology R&D. Concentrates public investment on excellent academic research in academic disciplines relevant to nanotechnology, and facilitates public-private partnerships between academia and business enterprises active in nanotech R&D and fabrication.

Notes: Annual budget corresponds to most recent available data from official programme websites describing the programmes; * annual budget corresponds to an annual average based on the allocation of a multi-year budget; PPPs: public-private partnerships.

3.2. Monitoring and evaluation strategies

Monitoring and evaluations are an important feature of programmes supporting industrial sectors, as they provide an important source of policy learning that may feed back into future policy cycles. Of course, targeting specific sectors is usually part of a wider industrial policy portfolio, which may include other forms of selective policy, such as targeting particular technologies, as well as horizontal measures. It follows that drawing clear conclusions about the benefits of initiatives for specific sectors is complex and findings would be context-dependent (Cook, 2016; SQW and Cambridge Econometrics, 2016; Warwick and Nolan, 2014).

Like all Austrian COMET centres, the Virtual Vehicle COMET centre is subject to impact assessments and ex-post evaluations that are based on a detailed, pre-defined monitoring and evaluation concept established by the centres' funding agency, the Austrian Research Promotion Agency (FFG). The Virtual Vehicle COMET centre is continuously monitored to trace progress towards its objectives, and the results across the centres are used to assess the COMET programme's overall activities. Internal mid-term evaluations at the level of the centre provide the basis for future funding decisions, based on a combination of qualitative and quantitative information, and are complemented by external final evaluations. According to an impact assessment of the overall COMET programme published in 2015 (OECD, 2018a), the programme has been successful in terms of high-impact publications, innovation outcomes, qualification of young researchers and the establishment of long-term (international) partnerships (Dinges et al., 2015). At the same time, the assessment found the programme had developed few new approaches to innovation, which have not yielded radical innovations.

The Israeli Innovation Labs programme only became operational in 2018 and is therefore still in its initial phase. No formal evaluation framework, including criteria for determining success or failure, seems to exist at this moment. A first ex-post evaluation of the Innovation Labs programme should take place in 2022. The development of the start-ups is monitored, not least because public support is repayable (at a rate of 3% per year) in the case of commercial success.

In the United States, Manufacturing USA commissioned Deloitte Consulting to conduct a third-party evaluation of the initiative in 2016 to assess specific outcomes regarding the programme objectives to: i) facilitate technology innovation and commercialisation; ii) accelerate manufacturing workforce development; and iii) promote sustainable ecosystems for advanced manufacturing. The evaluation was based on stakeholder interviews with participating agencies; site visits; interviews with independent external experts in manufacturing, including CEOs and leaders of Fortune 500 companies; collection and analysis of institute and programme documents; aggregation and analysis of institute data; crowdsourcing perspectives and feedback from more than 70 members across the institutes; and analysis of open-source reports, data and documentation, including government statistics.

The New York Nanotechnology Cluster consists of business enterprises and research institutes related to the nanotech industries. Research institutes receiving public funding are subject to regular evaluations. As the New York Nanotechnology Cluster consists of a large number of stakeholders, a formal evaluation strategy or framework does not exist for the entire cluster. However, the evolving concentration of nanotech research and fabrication has been subject to academic research on the interplay between public and private entities in funding research and fabrication facilities, as well as the economic impact of the cluster on upstate New York.

3.3. Critical dimensions

Israel's Innovation Labs programme enables open innovation processes by encouraging collaboration between specialised firms establishing an innovation lab and start-ups operating under the lab. The programme targets industries, technologies and expertise with potential to grow and develop new competencies and related economic activity in the Israeli economy. The programme's ability to incentivise collaboration in research and innovation, to benefit from access to complementary expertise, will be critical to its success. Start-ups can access technological infrastructure and established industrial expertise that would otherwise be time-consuming and expensive, helping to shorten the time span to achieve proof of concept. For the large and established specialised firms with substantial expertise in a specific field, this type of co-operation facilitates access to new and complementary knowledge that is critical to their innovation activities. The programme's funding model helps reduce the risks borne by the participating firms. The Israel Innovation Authority does not acquire equity in the start-ups, and repayments of the grants it has provided occurs only in case the products are commercially successful.

Manufacturing USA institutes address a wide range of technology issues (Bonvillian, 2017) compared to similar national initiatives (including on Industry 4.0), indicating that a revolution in manufacturing could have far-reaching consequences. It ensures R&D and technology adoption across a plethora of manufacturing enterprises, particularly SMEs, which often face tighter constraints than larger firms. Manufacturing USA uses private non-profit organisations to connect a network of companies and universities that develop standards and prototypes. It is an example of a technology partnership that also provides opportunities for both tacit and formal knowledge exchange, pooling of capabilities and specialties, agreement on common protocols and leveraging sponsorship sources through calls for private funds to match public funding. Such an organisation enables new forms of partnerships that cross sectoral boundaries, bringing to bear the portfolio of expertise and capabilities required to effectively address the "scale-up" gap between research and commercial production for advanced technology deployment. The public-private partnership model of Manufacturing USA institutes is another success factor. It facilitates collaborations that improve R&D investment in manufacturing, overcome problems of collective action in the sector, reduce barriers to innovation, enable better access to intellectual property, and cut risk and cost through shared access to assets. In addition, the evaluation found that the network's sustainability was critical to its outcomes (Bonvillian, 2017). This sustainability is ensured by a tailored portfolio approach that creates customer value, a critical mass and connectivity of institute members – which encourages others to join and remain as members – and the institutes' alignment with and stimulation of regional economic clusters. Moving beyond efforts to upscale existing institutes and programmes, and investing more in high-value, high-need workforce initiatives will be required to ensure the institutes' continued success. This will entail establishing adequate outcome-oriented metrics for workforce-related investments, ensuring a successful management of the institutes' portfolios.

In New York State, the initiatives and activities of public, private and academic actors have contributed to the New York Nanotechnology Cluster's success. The state leadership's vison of leveraging its emerging nanotechnology industry as a driver of regional economic growth is particularly notable. This commitment has been sustained by public investment independently of changes in the state's political leadership. Furthermore, business engagement has played a key role in driving the semiconductor industry, as well as in advancing the state's educational system and research infrastructure. University-industry research collaborations unconstrained by academic rules helped reduce administrative red tape and accelerated decision-making processes.

The Austrian Virtual Vehicle COMET centre supports a new form of co-operative research between science and industry aiming to incentivise strategic top-level research. The Virtual Vehicle helps align strategic interests between the automotive industry and academia. Engaging internationally renowned researchers and companies heightens the Virtual Vehicle's international visibility and promotes Austria as a location for internationally competitive research.

3.4. Conclusions

Support for strategic industrial sectors, notably in the manufacturing industries, includes both transforming existing industries and facilitating the emergence of strategic industries by using the potential of technological change for radical innovation. The future of manufacturing in advanced economies depends on businesses' ability to develop and benefit from technologies that open up radically new paths of innovation. Among others, biotechnology, nanotechnology, photonics, new materials and microelectronics are key enablers for technological innovations. As technological development in these areas is strongly science-driven, close and effective co-operation between industry and science is critical. Government policy tends to focus on funding R&D, including collaborative R&D between business and research. It also supports the development of regional clusters. For instance, the New York Nanotechnology Cluster in the United States was established through a combination of public and private investment in infrastructure. It also involved a public-private partnership supporting semiconductor research and manufacturing, considered as a strategic US industry. The New York Nanotechnology Cluster substantially supported the development of upstate New York's regional economy as a leading locus for nanotechnology R&D and fabrication. The cluster attracts public investment in support of excellent academic research relevant to nanotechnology, and facilitates co-operation between academia and business enterprises in nanotech R&D and fabrication. Based on a number of public-private partnerships, the cluster has leveraged multimillion-dollar investments to establish a financially and technically competitive environment for nanotechnology R&D. This also involved the collocation of university research, industrial R&D and business incubators. To maintain the cluster's attractiveness to firms, public investment has shifted to reinforcing, expanding and funding new research institutes for the nanotech industry.

In Austria, the Virtual Vehicle COMET centre combines co-operative research between stakeholders from academia and industry. The centre pursues innovation in new and promising technology areas in the automotive and rail sectors, based on industry-led co-operative research. Its activities substantially support the growth and internationalisation of the Styrian Mobility Cluster, which has evolved around a network of about 300 business enterprises and research institutes operating in the automotive, aerospace and rail industries.

In the United States, Manufacturing USA institutes are public-private partnerships focusing on critical advanced manufacturing technology with a strategic impact on the economy. Manufacturing USA institutes' research portfolio stands out by its breadth, indicative of the wide potential range of the next production revolution.

Israel's Innovation Labs programme is innovative in that it brings together the expertise of large multinational enterprises that want to grow and root themselves in Israeli innovation ecosystems endowed with the creativity and drive of local start-ups and entrepreneurs. It encourages co-operation between large and small firms, based on synergies derived from complementary capabilities, while reducing financial risks to the participating firms.

Finally, both the US SBIR programme (discussed in Section 2) and the Israeli Innovation Labs, stimulate innovation by incentivising and attracting SMEs and start-ups to align with the needs and capacities of a larger partner.

4. Transition towards new methods of production – Industry 4.0

4.1. Policy challenges and trends

The OECD has referred to the ongoing transformation of production in generic terms as the "next production revolution". This transformation is the result of the confluence of a range of technologies, including digital technologies, new materials, 3D printing, nanotechnology and industrial biotechnology. As a whole, the developments and convergence among these technologies could have far-reaching consequences for productivity, employment and skills, income distribution, trade, well-being and the environment.

The term "Industry 4.0", originating in Germany, "*... refers to the use in industrial production of recent, and often interconnected, digital technologies that enable new and more efficient processes, and which in some cases yield new goods and services. The associated technologies are many, from developments in machine learning and data science, which permit increasingly autonomous and intelligent systems, to low-cost sensors that underpin the IoT, to new control devices that make second-generation industrial robotics possible*." (Nolan, 2017)

The increased computerisation of manufacturing industries makes the distinction between industry and services less relevant, as digital technologies are connected to industrial products and services (European Commission, 2016). Many OECD governments have designed and implemented strategies and policies, and created new institutions, to accelerate Industry 4.0 in their own countries.

These developments have arisen in a context where labour productivity in OECD countries has been relatively stagnant for several decades. Raising labour productivity is essential to improving living standards over the long run. The imperative of productivity growth is compounded by the projected doubling of the ratio between economically dependent persons and economically active persons over the next 35 years. Industry 4.0 has the potential to effect important productivity gains in manufacturing. Furthermore, the increased digitalisation of manufacturing reduces the distinction between industry and services, with the potential to both create new services and raise productivity in a range of existing services. However, the evidence suggests that the diffusion and adoption of advanced forms of digitalisation vary greatly across countries, as well as between SMEs and larger firms. In addition, only a small share of firms are undergoing comprehensive digitisation, even in countries that are considered leaders in Industry 4.0.

The diffusion and adoption of these technologies by firms, and in some cases the public sector, is key to achieving the positive outcomes of Industry 4.0. This process involves both hardware and complementary intangible investments and know-how, from skills to new forms of business organisation (OECD, 2017a). Data are central to the new methods of production associated with the next production revolution, which will bring about profound change to the socio-economic fabric of work. Public understanding and acceptance will be key to the successful adoption of new production technologies.

A range of public policies affect the speed of diffusion. Accelerating diffusion is one of the core goals of many national strategies targeting the implementation and monitoring of the microeconomic framework conditions that determine the efficiency of resource allocation among firms. These policies range from regulations affecting the development and operation of the venture-capital sector to bankruptcy laws, competition policies and policies affecting labour-market efficiency. Furthermore, institutions that focus on the diffusion of technology – e.g. technical extension services, programmes that facilitate access to specialised skills and advice, and contract research systems and institutions – can also play a positive role, if well designed.

The diffusion challenge is particularly acute among SMEs, reflecting a range of characteristics among such firms. For instance, ICT specialists are generally less prevalent in SMEs, and the limited internal division of labour in SMEs can often mean there are too few staff with deep expertise in relevant technologies. At the same time, technology choice may become more complex as firms have to choose among a burgeoning number of fast-changing technologies and technology vendors eager to propose individual technology solutions. Search costs for reliable sources of information can be a significant drain on the internal resources of SMEs.

In many OECD countries, manufacturing R&D strategies are identifying new opportunities for domestic capture of value created through Industry 4.0. The promise of productivity gains through Industry 4.0 (in particular, ICT-enabled advanced manufacturing systems) is attracting significant attention. Similarly, the potential of Internet-based platform businesses to capture value from the online delivery of goods and services, and interactions with customers, is attracting interest.

Within the overall context of the transformations associated with the next production revolution, digitalisation is the major driver of industrial innovation. For governments, this implies a number of key challenges public policies need to consider to leverage digital opportunities for manufacturing and transform industries through new production methods (see Monograph 1 on digital innovation). As previously mentioned, national initiatives for advanced manufacturing have proliferated in recent years. These include Germany's Industry 4.0 initiative (Plattform Industrie 4.0), Manufacturing USA, Japan's Robot Strategy and the People's Republic of China's Made in China 2025 (O'Sullivan and López-Gómez, 2017). These initiatives aim to address the following key challenges and priority goals:

- **Seizing the opportunities of digitalisation for industrial innovation**, including the use of digitalisation in production and product delivery, the development and application of new digital technologies (e.g. artificial intelligence, blockchain, cloud computing), the provision of a conducive technical and legal (regulatory) infrastructure (including standardisation), and better integration of digitalisation in education programmes and lifelong learning initiatives. Many countries focus on the diffusion of Industry 4.0 concepts among SMEs (see, for example, the German Mittelstand 4.0 initiative and Plattform Industry 4.0, and Singapore's SMEs Go Digital initiative; on the Austrian variety of Plattform Industry 4.0 (OECD, 2019), see Monograph 1 on digital innovation). The German Industry 4.0 initiative takes a top-down approach, led by the government, pioneering companies and academia. Its key initiative, Plattform Industrie 4.0, co-ordinates digital transformation processes in the manufacturing sector, bringing together a wide range of stakeholders from the private and public sectors to focus on central challenges in the transition to Industry 4.0. The platform provides a basis for formulating actionable recommendations, guidelines, discussion papers and a consistent policy framework (BMWi, 2018; Ezell, 2018). The approach of Germany's Industry 4.0 initiative stands out as being strongly focused on developing standards for Industry 4.0 technology (European Commission, 2018a). This focus is less pronounced in other countries, where initiatives related to Industry 4.0 mostly support the development of new opportunities, such as new businesses models and "smart products" (Ezell, 2018).
- **Addressing potential skill bottlenecks.** The increasing use of advanced ICTs, such as data analytics, has boosted demand for new types of skills; yet a scarcity of specialist skills may hinder adoption of ICTs. Surveys point to the shortage of skilled data specialists as one of the biggest impediments to the use of data analytics in business. OECD data show that 7-27% of adults in OECD countries still have no experience in

using computers or lack the most elementary skills, and only 6% of people in the OECD area have the "highest level" of ICT skills. In response to the urgent need for skilled personnel, initiatives such as the Manufacturing USA in the United States or MADE in Demark, which involves a PhD programme in manufacturing, focus as much on skill development as on R&D.

- **Encouraging investments in R&D in key enabling ICTs**. The digitalisation of industrial production requires investment in R&D in digital goods and services, including the Internet of Things, data analytics and computing. Countries with enhanced capacities to supply and adopt these goods and services will be in the best position to benefit from first-mover advantages stemming from the digitalisation of production. The importance of investments in R&D is evident across countries. In the United States, four institutes within the Manufacturing USA network address smart manufacturing-related technologies and processes (Manufacturing USA, 2017), focusing on technology development in the areas of design, product development and systems engineering (Ezell, 2018).

This monograph covers three initiatives to spur the transition towards new methods of production – Industry 4.0: MADE, the German Industry 4.0 initiative and SME (Mittelstand) 4.0 initiative, and the Swedish Produktion2030 programme, one of the 17 Swedish strategic innovation programmes (Table 4).

Table 4. Transition towards new methods of production – Industry 4.0: Overview of policy examples

Policy initiative	Country	Period	Annual budget (EUR)	Brief description
MADE	Denmark	2014-19	10 million*; 47% of funding from business enterprises	An open collaborative initiative linking industry and academia nationwide to collaborate on industrial research projects that advance Danish manufacturing. SMEs can also obtain financial and knowledge-related support up to EUR 12 250 per company to participate in demonstration projects.
Industry 4.0	Germany	2011-present	22 million*; additional financial and in-kind contributions from private firms cover the operating costs of the Industry 4.0 platform	Maintaining and developing Germany's leading position in industrial manufacturing by increasing the sector's digitalisation; supporting research, networking of industry partners and standardisation by reinforcing comprehensive stakeholder dialogue to disseminate understanding of Industry 4.0.
SME (Mittelstand) 4.0	Germany	2015-present	44 million*	Supporting SMEs in the transition to Industry 4.0 through a network of 26 competence centres that help SMEs make better use of the opportunities of digitisation and prepare for upcoming challenges of the digital economy. Funding per centre amount to around EUR 1-2 million per year.
Produktion2030 (strategic innovation programme)	Sweden	2013-present	10 million*, 50% of funding provided by business enterprises	Supporting the Swedish manufacturing industry to become a leader in sustainable production technologies. The programme issues calls for collaborative research proposals between industry and academia between EUR 0.5-1.0 million per project.

Note: Annual budget corresponds to most recent available data from official programme websites describing the programmes; * annual budget corresponds to an annual average based on the allocation of a multi-year budget.

4.2. Monitoring and evaluation strategies

Many initiatives that facilitate the transition to Industry 4.0 focus on technology diffusion, particularly in SMEs. It is important to monitor and analyse the institutional design and operational models of technology diffusion institutions and initiatives as they are operating in a dynamically evolving environment. In this context, Shapira and Yuti (2017) recommend the use of evaluation metrics that "give more weight to longer-run capability development, rather than short-term incremental outcomes" and highlight the need for performance indicators that adequately reflect the systemic nature of new production methods.

Some of the new initiatives related to new production methods were put in place only recently and have not been evaluated so far. It is important, however, to define key metrics for measuring success early on. O'Sullivan and López-Gómez (2017) point out that phenomena such as technology and research convergence and systems complexity raise new questions with regard to the choice of evaluation metrics, warning that traditional metrics "may not adequately incentivise efforts to enhance linkages, interdisciplinarity and research translation".

Despite the challenges related to governments' relatively short experience with programmes supporting Industry 4.0, monitoring and (preparations for) evaluation are common to a number of such programmes. In Denmark, evaluation helps balance to some degree the high degree of autonomy of MADE as an independent association of stakeholders. At the request of Innovation Fund Denmark, a mid-term evaluation was commissioned in 2017 from an independent third-party institution (DAMVAD Analytics). The evaluation was based on data reported to MADE by participating firms, and focused on its impacts in terms of productivity and revenue growth. It assessed the preliminary results of the research projects financed under MADE, as well as the potential to disseminate MADE-funded research and new solutions for manufacturing processes across Danish industry. It also attempted to understand the economic and social returns of disseminating the technologies produced by MADE in Danish manufacturing companies.

Germany's SME4.0 Competence Centres initiative is subject to ongoing monitoring and evaluation commissioned by BMWi and carried out by an independent research institute (Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste). No evaluation reports have been published so far.

In Sweden, an evaluation of Produktion2030 from Technopolis has been commissioned by Vinnova, the Swedish Research Council for Environment and the Swedish Energy Agency as part of the evaluation of all 17 Swedish strategic innovation programmes. The evaluation is scheduled for 2020 and will identify the results achieved, including the impact to date on innovation in manufacturing. It will provide inform the agencies' decisions on pursuing funding and developing the programme. In addition, each funded project is required to submit a report to Vinnova one year after its termination in order to support continued assessment of the impact of the funds invested, including by quantifying the private-investment leverage ratio and changes in turnover.

Germany's Industry 4.0 Initiative was evaluated in 2016 by the European Commission's Directorate General for Internal Policies (European Commission, 2016). The evaluation compared different national approaches to Industry 4.0. It assessed qualitative information to understand the effect of disseminating Industry 4.0-related technologies among firms, specifically their impact on producing novel ways of creating value through technology adaptation, business models and the ability of SMEs to enter new production networks. The results were used to identify policy gaps and provide corresponding recommendations. However, a detailed assessment of the German Industry 4.0 initiative and its I40 platform, based on an established evaluation framework, has not been conducted.

4.3. Critical dimensions

In Denmark, the governance and design of MADE are critical to its effective implementation and operation, as its lean governance structures facilitate knowledge sharing across industrial and academic partners. Together with the initiative's bottom-up approach, industrial challenges are defined in accordance with industry needs. The basic structure of the initiative was designed by the academic and industrial partners involved. The board of directors and advisory board of MADE mainly comprise industry representatives, with minor representation from academia and none from the Danish government, which supported the development of strong partnerships between industry and academia. The initiative's strong project governance and open dialogue have enabled a productive approach to internal challenges.

Germany's SME (Mittelstand) 4.0 mobilises experienced partners (primarily from regional industry associations and Fraunhofer Institutes) with high competences in SME-related Industry 4.0 to provide better tailor-made services for SMEs. It provides incentives for research institutes, universities, industry associations and private-sector organisations to combine their resources and existing networks to further the initiative's goals. This approach may seem superior in terms of both cost and speed compared to setting up new greenfield centres. With limited resources, the initiative has succeeded in creating a comprehensive nationwide network of regional competence centres that facilitate the access of SMEs to the critical knowledge needed to carry out digitalisation projects.

In Sweden, Produktion2030 applied a bottom-up approach to achieve its objectives, entrusting stakeholders with major responsibilities to develop the programme. Production2030's success is evidenced by the strong interest of industry and research actors in participating in the programme (including by co-financing projects), ensuring its relevance to industry needs. The programme also empowers young researchers by having them lead expert groups. However, achieving and maintaining the desired balance between large and small enterprises, and especially a sufficient involvement of SMEs, is a persistent challenge. Furthermore, most projects concern process innovation, cost reduction and efficiency.

Finally, Germany's Industry 4.0 initiative has successfully transferred research into practice, particularly through its support of technology testbeds, which help produce quality mass-customised products at competitive costs.

4.4. Conclusions

The transformation of industries summarised under the term "next production revolution" is well underway in the OECD area and beyond. Many countries operate programmes and initiatives promoting Industry 4.0 under various headings and conceptual frameworks. Support for the development of skills and competences is as important as investment in R&D related to new technologies and production processes. A salient feature of these initiatives is the establishment of platforms (e.g. Plattform Industrie 4.0 in Germany) bringing together public and private actors to identify challenges, develop solutions and disseminate information. Diffusion institutions play a central role in the uptake of technologies relevant to Industry 4.0. Germany's SME (Mittelstand) 4.0 offers cost-effective services by building on existing regionally distributed institutions (including Fraunhofer Institutes) with strong competences in manufacturing technology. The initiative supports the pooling of resources by participating institutes, universities and private-sector organisations. In the United States, some Manufacturing USA institutes specialise in "smart manufacturing"-related technologies and processes.

In all of these platforms and networks, governance structures play a decisive role in ensuring that research is aligned with the evolving needs of industry. One of Sweden's pioneering strategic innovation programmes, Produktion2030, supports industry-led consortia with a high degree of autonomy (hence referred to as mini-Vinnovas). Denmark's MADE is organised as an independent association funded primarily by Innovation Fund Denmark, with a lean governance structure led by industry and academic partners, and minimal government involvement.

Germany's SME (Mittelstand) 4.0 initiative features some innovative approaches supporting the transition towards new production methods. In particular, it uses existing networks of participating institutes and encourages stakeholders to pool resources. This helps the programme contain costs significantly, compared to the investment needed to build new facilities. Furthermore, accessing established networks of industry and research partners is economically sound, and ensures the institutes' research is aligned with their business partners' application-oriented needs.

The Danish MADE initiative is organised as an independent association. The platform's leadership consists entirely of industry and research partners, with no government involvement. MADE expands the knowledge available through participating firms, innovation conferences, workshops, research and industrial visits with manufacturing companies that are not directly involved in the research projects.

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