Addressing societal challenges through disruptive technologies

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Innovation for Transformation –
Fostering innovation to address societal challenges

Results Paper 3

Addressing societal challenges through disruptive technologies

Results Paper 1: Good practices in mission-oriented innovation strategies and their implementation
Results Paper 2: Networking and exchange in mission-oriented innovation processes
Results Paper 4: Fostering innovative startups in the pre-seed phase
Results Paper 5: An agenda for the future: Innovation for transformation

Authors
Hendrik Hansmeier
Knut Koschatzky

Scientific analysis

Fraunhofer ISI

REINHARD MOHN PRIZE 2020

Fostering Innovation. Unlocking Potential.

As part of the "Fostering Innovation. Unlocking Potential." project, which was launched within the framework of the Reinhard Mohn Prize 2020, we have conducted a global search to identify noteworthy examples of innovation-promoting initiatives, mechanisms and strategies that could be applied to promoting innovative capacity in Germany and Europe. One objective of our efforts has been to ensure that Germany remains technologically – and thus economically – competitive. But another key objective here is to address societal challenges while ensuring humane, democratic and inclusive economic development. We start from the premise that two paradigms – "strengthening innovation and technological competitiveness" and "solving societal problems through innovation" – can be combined to mutually reinforce each other.

Innovation for Transformation

Although Germany regularly performs well in international rankings of competitiveness and innovative capability, a closer look at things shows that despite all its strengths and the confidence key economic indicators suggest, the intensity of innovation – particularly in key digital technologies – in Germany as well as Europe has been on the decline in recent years. Moreover, Germany has delivered hardly any disruptive innovations, that is, those innovations that fundamentally change the rules of a market or consumers' usage behavior. This is problematic both in terms of economic as well as societal considerations – particularly since the answer to many of the societal challenges we currently face might very well be found in the innovations of leapfrogging technologies. Our project aims to help unlock this potential and make the solutions it delivers a reality.

With this vision in mind and in line with Reinhard Mohn's vision of "Learning from the World," the Bertelsmann Stiftung conducted extensive global research on good practices that are applied in various international contexts. In cooperation with the Fraunhofer Institute for Systems and Innovation Research ISI, the findings have been summarized in four results papers. Each paper has a different focus but explores the extent to which competitiveness can be linked with mission-driven approaches to societal issues.

- The **first paper** outlines the theoretical framework used for the global study and draws on selected international case studies to show how a broader umbrella strategy for innovation can effectively combine technological and economic competitiveness with efforts to solve societal issues. The paper explores in particular the aspects of governance involved with innovation policy and shows what Germany has to learn from examples in other countries.

- The **second paper** examines how the development and diffusion of new and societally relevant technologies can be promoted through appropriate networking mechanisms that engage actors in business, research, politics and civil society in open innovation processes. The paper thus features several examples of good practices found in other international contexts that both Germany and Europe can learn from.

- The **third paper** (present study) takes a close look at how the framework conditions for disruptive innovations in particular can be strengthened. It also describes the lessons learned in countries such as Israel, Japan and the United States that are relevant for Germany in its efforts to become a top location for innovation.

- The **fourth paper** is devoted to the question of how to improve the conditions for establishing and growing societally relevant (high-tech) startups in their initial phase of being founded. The paper thus presents a variety of good practices from examples around the world and discusses their key takeaways.

- **Conclusions** derived from all four papers are integrated into the **"An agenda for the future: Innovation for transformation"** publication.

Each paper is available at www.bertelsmann-stiftung.de/innovation-for-transformation-en.

In the future, only communities that face up to global competition and repeatedly demonstrate their ability to innovate and perform can succeed and endure.

Reinhard Mohn

CONTENT

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Key findings

- Based on research into good practices, the present paper analyzes various strategies and structures for the active promotion of disruptive innovation and formulates specific recommendations for German innovation policy. The examples of the United States, Israel and Japan are given particularly close attention.

- Disruptive innovations are inventions that trigger radical changes within societies, cultures and political systems. The processes of invention, adaptation and improvement associated with such innovations have been changing the world at a fundamental level for millennia (e. g., the invention of the wheel, the printing press or the steam engine), potentially helping people to cope with societal challenges. In modern terms, we might say that they have contributed to the fulfillment of what we now refer to as "missions."

- During the first phase in which mission-oriented approaches were employed (the 1950s and 1960s), technology and innovation policy was directed primarily toward achieving national goals (such as the moon landing). More recently, however, the focus has increasingly shifted toward efforts to address global challenges, or missions, such as dealing with climate change, combating disease, or establishing sustainable consumption and production practices.

- For its part, Germany's innovation policy has increasingly sought to engage with societal challenges, while promoting the emergence and diffusion of (disruptive) innovations with the potential to generate holistic solutions. This work has included the recent launch of an agency specifically focused on such disruptive innovation (SprinD). Moreover, the German innovation system features a high level of scientific and technological expertise, both with regard to basic and applied research and development.

- However, German economic and technological development is characterized by considerable path dependencies. Sectors such as the chemical industry and mechanical, automotive and electrical engineering are strong within traditional product fields (e. g., the auto industry's facility in optimizing the internal combustion engine). Making gradual improvements to products, or so-called incremental innovation, is also a German strength. Nonetheless, the country is less successful in carving out radical new paths and new dynamic markets, as takes place in the United States or China, for example (e. g., electromobility, digitalization, software or IT development). This results in a tendency toward inertia, with a strong focus on already-established fields.

- For this reason, the present paper argues that the existing institutional structures promoting (disruptive) innovation in Germany must be better networked and focused more strongly on facilitating disruptive innovations capable of solving societally relevant problems. In this regard, we can learn from the successful examples of the United States, Israel and Japan.

- Since the 1950s, the United States' Defense Advanced Research Projects Agency (DARPA) has promoted disruptive technological innovation (e. g., by assisting in the invention of the internet and of GPS technologies) by engaging in high-risk and financially intensive research and development, a process that has entailed – and accepts – failure. As an active change agent, DARPA is particularly focused on developing advanced information technologies (IT).

- In Israel, one of the world's most research-intensive countries, innovation policy is deemed a matter of vital importance, and is largely guided by the Israel Innovation Authority (IIA). This has produced a notably open innovation system with strongly networked actors that addresses societal challenges. Most of the IIA's support goes to private sector actors, who help push forward the development of technological innovations and thereby contribute to the country's technological competitiveness.

- Japan's "Impulsing Paradigm Change through Disruptive Technologies" (ImPACT) program seeks to promote disruptive technological innovation. Due to its considerable openness in terms of topics covered, it is characterized by a flexible project-support model and a focus on market demands. This program-based support model enables the development of high-risk R&D projects that in turn stimulate societal and economic change.

- These and other international examples show that disruptive innovation can be successfully promoted in a variety of different ways, with national objectives retaining their great importance.

These observations allow us to derive a number of key lessons for German innovation policy:

- Long-term, open-topic project support with ambitious goals and a high tolerance for risk should be expedited, as this fosters the emergence of disruptive innovations. As the DARPA example shows, funding high-risk research projects can trigger the emergence of new markets and generate significant societal benefit. This requires project- or research-funding periods longer than the two to three years typical in Germany and in Europe more generally.

- Transdisciplinary working methods in research and educational settings should be promoted, so as to overcome rigid thought patterns and career paths within scientific fields and disciplines. Developing ideas across disciplines and establishing networks between researchers increases the chances of producing disruptive innovations and new solutions. However, this requires overcoming the strictures of traditional scientific career patterns, freeing researchers to engage in high-risk research projects while recognizing these activities as a regular aspect of career development.

- Cooperation beyond the traditional channels of exchange between the research and business sectors should be intensified. In the areas of IT, the environment, sustainability and energy, numerous innovations have emerged in recent years from outside the academic research community or the circle of established companies (e. g., booking and e-commerce portals, decentralized energy systems, sharing-economy activities). There is also a need for greater openness to new groups of civil society actors. Including such entities could strongly facilitate needs-based development, thus contributing in turn to the success of (disruptive) innovations. Such exchanges should include a European and global perspective. For example, entities can engage in cross-border cooperation to draw on knowledge and expertise that is domestically lacking or in scarce supply.

1.

Disruptive innovation: Societal progress through radical change

Inventions have transformed the world. How would religion, culture, science or the economy have developed had Johannes Gutenberg not invented the moveable-type printing press in the middle of the 15th century? How would industrialization and economic development have proceeded had Denis Papin not invented the basics of steam-engine technology, which were then further developed by Thomas Savery and Thomas Newcomen and perfected by James Watt? Would information technology have evolved into what we recognize and use today if Guglielmo Marconi had not invented wireless telegraphy at the end of the 19th century, if John Bardeen, Walter Brattain and William Shockley had not developed the transistor at Bell Labs in 1948, and Jack Kilby had not invented the integrated circuit in 1958?

This list could go on without end, demonstrating by example how inventions are able to spark radical change. Inventions that have reached the market, are successfully commercially exploited and are ultimately used are referred to as innovation (as opposed to the invention itself). Inventions with the potential for change described here are referred to as disruptive innovation (or *Sprunginnovation* in German). In English-speaking circles, other descriptors such as "radical" or "breakthrough" innovation are also used.[1]

The examples provided above also illustrate that in many cases, a single invention in itself is not enough to trigger change on this scale. Rather, multiple developmental steps are necessary to produce a disruptive innovation. Yet even this process may not reveal its full potential immediately. For this to occur, there must be a favorable, supportive environment in place, and there must be buyers and users that help it to make its disruptive mark. The societal impact of the moveable-type printing press became visible only as more and more books were printed, and as a broad population learned to read and write as a result.

Inventions such as the printing press, steam engine and wireless telegraphy have changed the world.

1 These terms are not used as synonyms, because they reflect different innovation strategies and levels of innovation; however, they describe the same phenomenon as disruptive innovation.

The potential of the integrated circuit was fully realized only after techniques for miniaturizing these components were developed, thus enabling mass production. Disruptive innovations do not refer to individual, singular phenomena, but rather to processes of invention, adaptation and improvement that unlock the potential for radical breakthrough. Rather, breakthroughs carrying the seeds of change may realize this potential over the course of time – or they may not. As a rule, it can be determined only in retrospect whether an innovation has achieved the character of a disruptive innovation.

Disruptive innovations can radically change societies, cultures, religious and political systems, patterns of participation and inclusion, distributions of wealth and poverty, and the way that people interact with one another through digital technologies (as currently seen with social media). They are of vital importance especially for efforts addressing societal challenges in the areas of climate change, energy, the environment, health and security – efforts that we refer to here as missions. They can contribute to sustainable economic growth, to the creation of new and high-quality jobs, and to significant improvements in the quality of life (BMWi and BMBF 2018: 1).

Disruptive innovations can help us overcome societal challenges.

Germany's weakness: Incremental rather than radical change

For all of these reasons, there is a strong political interest in promoting disruptive innovation. In Germany, the term "disruptive innovation" (*Sprunginnovation*) was used as far back as 1993, in the Federal Report on Research, in connection with providing support to small and medium-sized enterprises (SMEs) (Bundesregierung 1993: 96 and 245). Yet the concept found its way back into the political discussion only with the coalition agreement struck between the CDU, CSU and SPD on February 7, 2018, and in the federal government's subsequently produced High-Tech Strategy 2025 (BMBF 2018).

In previous years, innovation policy had centered on the promotion of new technologies (the German federal government's first High-Tech Strategy, adopted in 2006, had a strong technology focus). However, with the adoption of the new mission-oriented approach, societal problems and the development of solution strategies were made a focus of innovation policy (see Results Paper 1 in this series). For example, the High-Tech Strategy 2025 adopted in 2018 addresses six areas in which pressing societal challenges require urgent action: "Health and care," "sustainability, climate protection and energy," "mobility," "urban and rural areas," "safety and security," and "economy and work 4.0." The intent here is to generate contributions and solutions for the looming challenges with an innovation-promotion program that accepts projects ranging across the technological spectrum. It is anticipated that disruptive innovations make a significant contribution in this regard. Such breakthroughs are expected to bolster innovative capacity in Germany, while additionally unlocking potential enabling the solution of societal problems.

Although Germany is credited with a good innovation record in its traditionally strong industries such as automotive engineering, mechanical engineering and electrical engineering (acatech 2018: 9), it is weaker with regard to innovations that generate new markets and suppliers, and which create new demand (e.g., in the area of internet platforms). With this in mind, the federal government moved in early 2020 to adopt the Research Allowance Act, a tax instrument focused on promoting research and development. Particular focus here is placed on mobilizing additional research resources within SMEs, and on supporting knowledge and technology transfers from academic research institutions to the private sector (EFI 2020: 18). Germany is particularly weak with regard to technology transfers for the purposes of developing market-ready and radically new applications, a fact that hampers the emergence of disruptive innovations (acatech 2018: 9). The Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Energy recently founded a new agency tasked specifically with promoting disruptive innovation (SprinD). It is expected to address precisely this issue, contributing to the solution of societal problems with mechanisms such as innovation competitions and cutting-edge projects (BMBF 2018: 50; BMBF 2020). However, these developments remain in their infancy, and the impact of these solutions remains to be seen. It is therefore well worth a look at other countries that have already-established structures promoting disruptive innovation.

The present study is thus based on a review of the institutional conditions that contribute particularly effectively to the development of mission-oriented disruptive innovation. To this end, the study on the one hand critically evaluates the current structures making up the German innovation system; on the other, it describes promising elements and solutions at work elsewhere (in the United States, Israel and Japan), and discusses the degree to which they may be transferrable to Germany. Specifically, this paper focuses on answering the following questions:

- **What are disruptive innovations, and how can they be generated today?**
- **What is the situation in Germany?**
- **What can good practices in other countries teach us about the German environment?**

The development of breakthrough applications is lagging in Germany.

2.

Concepts and conditions that foster disruptive innovation

Although radical innovations have periodically appeared for thousands of years (e.g., the invention of the wheel), the idea of disruptive innovation was foregrounded in recent times by the first phase of the mission-oriented approach pursued in the technology and innovation policies of the 1950s and 1960s.[2] At that time, a "mission" did not mean an orientation toward societal concerns or global challenges; rather, the focus was on reaching national goals such as the moon landing. Doing so required finding wholly novel solutions, especially in a dimension that led to a major technological leap forward. Disruptive innovation was defined with reference to this groundbreaking technological progress. Beginning in the late 1950s, many countries such as the United States tasked specific agencies with promoting disruptive innovation. For example, the DARPA (originally titled ARPA when established in 1958) was given responsibility for defense-related innovations, while NASA was given a similar mandate in the area of manned spaceflight.

The German rendering, *Sprunginnovation*, is an invented term used to express this concept. The term "disruptive innovation" is the most widely used term internationally in reference to the phenomenon examined in this paper.[3] Disruptive innovations can be defined as those that modify the development path, change the technological paradigm, and present both opportunities and challenges for those engaging in business (Christensen 1997; Guo et al. 2019; Momeni and Rost 2016). One such example is digital photography, which has led to changes in camera technology and user behavior, as well as in the services sector (e.g., the closure of photo-development laboratories).

Since the 1950s, countries like the USA have commissioned agencies with the task of fostering disruptive innovation.

2 See Results Paper 1 in this series, which outlines the history of innovation in the 20th century.
3 Discussed for the first time in the English-language literature by Bower and Christensen (1995).

Disruptive innovations may initially be inferior to rival products or services due to existing demand structures (Govindarajan and Kopalle 2006). For example, the first steamships were inferior to sailing ships as a consequence of their comparatively poor maneuverability (the paddle wheel was originally located in the middle of the hull). Only with the optimization of the paddle steamers for river shipping were steamships introduced on a widespread basis for global freight and postal traffic. This example illustrates that under some circumstances, new characteristics may attract customers only from emerging or niche markets (river shipping in the example of steamships). Subsequent developments are then required to create the functionalities valued by mainstream customers. At that point, a level is reached at which the innovation begins to capture a larger share of the mainstream market.

Given this time lag, current market leaders often fail to recognize the threat posed by disruptive innovations. A disruptive innovation shifts market performance metrics and consumer expectations by offering radical new functions, a jump in technical standards, a new way to use existing products or new forms of ownership. Examples of such transformations can be found in mobile communication (mobile phones and their applications as a basis for new app-based business models), in the automobile industry (electric instead of internal-combustion engines), and even with regard to societal habits (sharing and repairing instead of owning). Changes of this kind enable the potential of the disruption to be realized (Hardman et al. 2013; Nagy et al. 2016).

Disruptive innovations have a profound impact on markets, technical standards and consumer behavior.

The printing press had disruptive potential that led to an unprecedented dissemination and expansion of knowledge, as well as societal reforms. The use of machines led to completely new capabilities and applications in production and transportation. Wireless communication and the miniaturization of electrical components and computers have contributed to significant cost reductions and productivity gains, while creating new products and services, providers and markets. Each of these resulted from a variety of innovations that were responsible for the breakthrough only in combination; their effect was to drive previous products and services from the market (e. g., horse-based transport) and produce significant changes in usage and behavior (e. g., acquiring information via the radio, TV or social media). Over time, new needs have arisen (e. g., industrial mass production, new models of communication), and significant changes have rippled across society and the economy (e. g., broad-based access to knowledge and information, or the emergence of new industries and economic sectors).

The interface between disruptive innovation and the mission-oriented approach

There are three definitions commonly applied in the German-speaking world that are specific to the terms "disruptive innovation" or "breakthrough innovation":

- In its High-Tech Strategy 2025, the German federal government refers to innovations that are "characterized by radical technological novelty and/or disruptive market changes" as breakthrough innovations (BMBF 2018: 48).

- The Key Issues Paper on the Agency for the Promotion of Disruptive Innovations (Bundesregierung 1993) equates these with groundbreaking developments.

- In its 2019 annual report, the Commission of Experts for Research and Innovation (EFI 2019: 157) defines disruptive innovations as "innovations with the capacity to effect significant transformations of markets, organizations and societies and which harbor major value-creation potential".

Thus, there are clearly different ideas about the specific character of disruptive innovation, both with regard to its technological dimension and its economic and societal consequences.

The conception of disruptive innovation employed in this paper can be summed up in the following definition (adapted from Cuhls et al. 2019):

Disruptive innovations are innovations offering performance-related features, ranges of product choice and end-use applications that – due to significantly better cost and benefit relationships – create a new dynamic market or achieve a high level of market penetration in existing markets.

Disruptive innovations can arise through entirely new technological approaches, novel business models or new combinations derived from the interplay of previously unconnected innovation processes. They displace older products, services and providers from the market, or expand the previous spectrum of offerings (niche markets). They are associated with new forms of consumption and new social practices, trigger significant behavioral changes (system level), and/or generate and serve new needs. In so doing, disruptive innovations can make significant contributions to economic development, and can even contribute to the solution of overall societal problems, for instance by helping to address climate change, combat diseases or establish sustainable consumption and production practices. Because these challenges have a global dimension, mission-oriented disruptive innovations with societal relevance are both appropriate and necessary when seeking to initiate far-reaching changes.

The literature notes that disruptive innovations can be generated only in a rich (comprehensive) and complex innovation system (Bonvillian 2018). Innovation-systems research has found that national, institutional, organizational and societal conditions all have an impact on the emergence and subsequent course of innovation (Nelson und Rosenberg 1993). Moreover, societal and sociopolitical factors have a significant effect on the acceptance of such innovations. From this, it is clear that according to the current understanding, a disruptive innovation is something more than even a major technological stride forward. Similarly, the conditions of origin are more complex than can be produced solely through publicly funded agencies or programs.

Fundamentally, disruptive innovations cannot be planned or ordered, although the expenditure of significant resources does allow national visions and missions to be achieved with the help of (disruptive) innovations. But even this is possible only if the prevailing societal, political and economic conditions do not stand in the way of the development and implementation of groundbreaking ideas.

Oftentimes, there are barriers in place that make it more difficult or even impossible to bring good ideas to market. For example, barriers and problems may arise from the characteristics of innovation processes. Because something entirely new is to be created, there is uncertainty as to how and whether this will succeed, and whether there may not already be better solutions coming to market at the same time or shortly afterward. In the literature on the subject, this uncertainty is explained with reference to imperfect competition, a lack of transparency and information asymmetries. While routines are one means of reducing uncertainty ("We've done things this way before, and it has worked, so we'll do it this way again"), this creates path dependencies that can have a negative impact on the willingness to develop and test innovations. Multiple sources of major uncertainty exist in all areas – meaning within companies, within the economy more generally, in politics and in the society at large. Three specific dimensions of uncertainty can be identified, each representing systematic obstacles and barriers to the emergence of disruptive innovations (Cuhls et al. 2019):

1) **Uncertainties related to creation:** Questions of technological feasibility, about integration into and effects on value chains, about the provision of services, or about the combination of product and service offerings;

2) **Uncertainties related to markets and users:** Questions about the emergence of new markets, needs and consumer preferences, about the impact on existing markets, and about the willingness and capability to utilize and further develop disruptive innovations;

3) **System-related uncertainties:** Questions regarding the legal environment, necessary infrastructures, and dependencies on other products and services. This also includes the degree to which the "losers" – that is, existing products and services that may represent competition – may be able to retain a foothold within the market.

While uncertainties having to do with the creation process, markets and users lie primarily on the innovator's side, the system-related uncertainties relate to the underlying framework conditions defined by the prevailing innovation system and its organizational and regulatory design. Figure 1 lists the relevant dimensions in this regard and presents the structure of inquiry for the following chapters.

Of course, the presence of institutions and practices representing each of these dimensions is no guarantee of success in producing disruptive innovations; however, it does facilitate their creation.

FIGURE 1
DIMENSIONS OF THE INNOVATION PROCESS

Source: Authors (adapted from Cuhls et al. 2019)

3.

Disruptive innovation processes in Germany still in infancy

In Germany, two primary elements form the strategic framework for innovation policy and innovation funding: First, the federal government's High-Tech Strategy 2025, entitled "Research and Innovation that Benefit the People," and second, the Horizon Europe framework program for research at the European level. Both framework strategies are focused on areas of activity such as health, security and climate change that pose major societal challenges and offer an opportunity to develop mission-oriented solutions (BMBF 2018).

Future promotional measures here in Germany have several objectives: to further develop the areas of expertise that will constitute Germany's future technological foundation; to secure and expand the skilled-worker pool through education and training programs, as well as through occupational health programs; and to strengthen societal inclusion by integrating users into technology-development processes. Another goal is to create an open and agile culture of innovation and risk-taking; this is to be achieved by promoting disruptive innovation, improving the transfer of basic-research results into commercial application, strengthening the entrepreneurial spirit, and intensifying national and international cooperation through knowledge and innovation networks (BMBF 2018).

In recent years, innovation-policy paradigms have changed. Rather than focusing primarily on providing support for technology development, they have taken on a transformative character, promoting the emergence and diffusion of innovations helping to create holistic solutions to societal and environmental challenges (e. g., in the context of the decarbonization of the economy, or efforts to arrest or mitigate climate change). In doing so, they take a systemic perspective. This requires that all relevant actors be involved, and that any solutions address technologies, regulations, infrastructures, value chains and existing policy measures. Innovation policy and funding programs of this kind are evidence-based, which means that policy decisions are based on scientific knowledge and facts (Edler and Fagerberg 2017).

Key principles within the strategic framework for innovation policy are presented in Figure 2.

FIGURE 2
PRINCIPLES OF INNOVATION POLICY IN GERMANY

RESEARCH AND INNOVATION

- Conceive innovation to be more than the development of technology
- Take non-technical and social innovations into account
- Establish innovation as an instrument of transformative change

COOPERATION AND TECHNOLOGY TRANSFER

- Promote cooperation and open communication through alliances, networks, clusters engaged in the open exchange of information (open science, open source), transfer and diffusion

MARKET/INTERNATIONAL ENGAGEMENT

- Take into account the needs of society and ensure involvement (participation)
- Define missions and solutions collectively
- Treat resource and energy efficiency as important policy principles
- Consider evidence on the adaptation and implementation of policy instruments through learning, mandatory evaluation and foresight

SOCIOPOLITICAL FRAMEWORK

- Government as a proactive agent of change in which innovation is promoted through public procurement (national and international)
- Coordination within and across ministries that involves civil society

Source: Authors (drawing from BMBF 2018)

The future environment for innovation promotion in Germany and Europe will be defined by the design of German innovation policy, its objectives, paradigms and principles, along with the mission-oriented cornerstones of European research, technology and innovation policy – the latter of which are currently furnished by the Horizon Europe framework program for research. One new aspect in this regard is the promotion of disruptive innovation by an agency dedicated specifically to this task (BMBF 2018).

SprinD – The German Federal Agency for Disruptive Innovation

As one of its objectives, the 2018 coalition agreement in Germany specified the development of new instruments able to promote disruptive innovation and technology transfer (Koalitionsvertrag 2018). The High-Tech Strategy 2025 fleshed out this goal, announcing that an agency for disruptive innovation would be founded; the objective was ultimately implemented with the creation of that agency on December 16, 2019, in the form of the Leipzig-based SprinD GmbH (BMBF 2018; BMBF 2020).

The model for SprinD is the U.S. Advanced Research Projects Agency (ARPA), founded in 1958 and renamed as the Defense Advanced Research Projects Agency (DARPA) in 1972. ARPA and DARPA funding activities have been responsible for many disruptive innovations, such as Arpanet, the early network from which the internet evolved. Although the United States and Germany offer very different environments for innovation, and DARPA has a strong defense-policy orientation, policymakers believe that a dedicated agency should be able to increase the quantity of disruptive innovations here in Germany as well.

In the original plans, the agency was to have a budget of €116 million in the startup phase, lasting from 2019 to 2022. Over a 10-year period, the plans stipulate a budget of around €1 billion. Thus, the agency is meant to take on an important role in the German innovation ecosystem.

The agency's objectives are to identity and promote research ideas with the potential to spark disruptive innovation, with the ultimate goal of solving specific problems relevant to society or potential users. The aim is to generate highly innovative products, processes and services that open up new high-tech fields, markets, sectors and even new business models for the German economy.

According to the key issues paper discussing the agency's creation, its work is to be strongly influenced by the individual experiences and ideas of a rotating expert staff. Employees with time-limited contracts (creative innovation managers), provided with considerable freedom of action, are to participate in the idea-generation and project-implementation process; this is expected to help make innovation projects more successful. One intention here is to integrate a comprehensive user perspective that drives and guides the innovation process even at an early stage, well before market introduction. The agency is also to serve as a point of contact for creatives and investors.

Three core tasks are envisioned for the agency. It is to:

1) Scout for ideas with the potential to produce disruptive innovation.
2) Fund research and development projects from the basic-research stage to the point of being ready for application.
3) Act as a transfer hub, or central contact point and catalyst, for ideas, projects, market analyses and the founding of new startups. In doing so, it is to keep abreast of international developments at all times.

In performing these tasks, the agency is to cooperate with private sector businesses, academic research institutions, civil society groups and policymakers; in this regard, the government and state will play a special supportive role as a potential customer, legislator and regulator, wielding significant influence over the overall environment in which the innovations are to be developed.

Three instruments form the basis for the agency's work:

1) Innovation competitions designed to elicit visionary responses to key societal challenges, which in turn help mobilize actors, trigger highly innovative activities and generate a high level of public attention.[4]
2) Cutting-edge projects with a duration of three to six years, whose results are to be translated into concrete applications.
3) Innovation managers (with time-limited contracts of five to six years) who propose problems to be addressed, make funding decisions, oversee the course of projects and provide support in bringing project results to market.

According to Rafael Laguna de la Vera, head of the Federal Agency for Disruptive Innovation, about 270 ideas and project proposals had been received as of September 2020.[5] From these, nine projects had been selected and funded. As of that date, an additional 10 were on the verge of receiving funding, and another 10 were under review. The agency additionally planned to publicly highlight one of its projects every month in order to raise the public profile of the relevant issues and the innovators involved. Even for the agency itself, it remains unclear whether there are genuinely disruptive innovations among its chosen projects. Determining this will require a perspective informed by the passage of as much as 10 years; thus, selecting the projects necessarily involves a conscious aspect of risk.

Strengths and weaknesses of the German innovation system

The German innovation system, the framework for promoting and realizing disruptive innovations, features a high level of scientific and technological expertise in both the basic and applied research and development sectors (particularly with regard to medical technology and mechanical, automotive electrical and chemical engineering). Germany's strengths lie in generating innovations that build in an evolutionary sense on existing technologies, products and services. The research and educational system supports these strengths through a differentiated basic and applied research landscape, a high level of interdisciplinary interaction in applied research, and a practice-oriented vocational (dual) education system.

These positive and successful development paths result in inertial tendencies with a strong focus on engineering fields. The marked culture of incremental innovation limits the opportunities and reduces the willingness to develop disruptive innovations. Large companies are the driving force behind innovation in Germany;[6] however, such entities are not typically where disruptive innovations originate. In consequence, the German innovation system has not to date been notable for producing comprehensive disruptive innovations.

Strengths and barriers within the key dimensions of the German innovation system depicted in Figure 1 are summarized in Figure 3.

Building on the analysis of the German innovation system with regard to disruptive innovation, we formulate the following key hypothesis: Disruptive innovation, in the context of mission-oriented policies, can offer solutions to societally relevant problems. However, such innovation may constitute only one aspect of a solution. Moreover, special agencies tasked with promoting disruptive innovation are not the only way of facilitating such innovation-driven solutions. Disruptive innovations are phenomena that can occur over a period of time. However, there is no natural law that renders them an inevitability.

From this, we can derive the following thesis:

THESIS

Institutions for disruptive innovation:
The existing institutional structures promoting (disruptive) innovation in Germany must be better networked and more strongly focused on facilitating disruptive innovations able to solve societally relevant problems.

4 In March 2019, even before the agency's official founding date, the BMBF launched the first three pilot innovation competitions: "Energy-efficient AI system," "Replacement organs grown in the laboratory," and "World storage." 5 Time for knowledge: Digital theme week. Session "Digitalization in the private sector & academia: Rapid change: Digitalization and disruptive innovation in Germany," September 14, 2020. 6 According to ZEW, infas and Fraunhofer ISI analyses on innovation in the German economy, fully 71 percent of innovation-related expenditure is made by companies with 1,000 or more employees. However, this group constitutes just under 0.5 percent of all German companies (figures for 2017, see ZEW, infas and Fraunhofer ISI 2018).

FIGURE 3
STRENGTHS AND BARRIERS IN THE GERMAN INNOVATION SYSTEM

STRENGTHS	BARRIERS
Research and innovation support	
• Broad spectrum of state funding mechanisms (institutional as well as project-based and joint funding), tax-based R&D support. • New support and technology-transfer instruments (e. g., clusters, research campuses, innovative universities, real-world laboratories). • Some support based on specific topics or technologies, but other elements open to all types of technology.	• Support measures are withdrawn upon market introduction, due to legal restrictions on state aid. • High-risk projects do not receive support • Instruments and programs are not flexible enough for novel ideas / Lack of new combinations of support instruments. • Gaps in support (valley of death) with regard to making specific adaptations readying innovations for market. • Financing gaps with regard to adapting innovations and transferring technology to new startup companies (lack of venture capital in Germany).
Research system	
• Differentiated research landscape for both basic and applied research. • Interdisciplinary activity is more developed in applied research than in basic research.	• Strict disciplinary thinking often prevails within university settings; career paths are focused within individual disciplines. • Due to staff discontinuities in research institutions (time-limited contracts), university system functions on time frames too abbreviated for long-term research projects. • University system rewards publications, but not high-risk research or engagement with speculative ideas.
Education and training	
• Strengths of the practice-oriented vocational (dual) education system.	• Vocational education still focuses on specific disciplines and/or technologies.
Cooperation and technology transfer	
• Well-developed culture of cooperation within the private sector and between research institutions and private sector entities, often along value chains; funded by the state and by individual projects. • Many well-developed channels for technology transfer between research and private sector entities; transfers are given policy support.	• Cooperative ventures often take place between entities with a similar disciplinary/technological background. • Policymakers, and even the parties involved, still tend to conceive of technology transfers as between research institutions and companies, lacking involvement by other organizations or societal groups. • Open-innovation culture is developing (where possible), but is not yet a lived daily process. • New actors (organizations beyond research institutions and private companies, societal groups) largely remain excluded from technology-transfer activities (although initial examples of creative and real-world laboratories are emerging).
Market/international engagement	
• Present on the world market with technologically high-quality medium-tech products, little cutting-edge technology, incremental innovation is a strength. • Links between products and related services (strong customer relationship). • Significant degree of international scientific and technological cooperation.	• No market leaders in areas of global digitalization or novel digital products and services. • Research system does not yet sufficiently exploit potential for internationalization.
Sociopolitical framework	
• Considerable technical aptitude within the population. • Increasing interest in climate-, environment- and energy-policy issues and implications. • Rising levels of societal engagement among broad sections of the population. • Increased awareness of the Sustainable Development Goals (SDG).	• High level of risk-averseness, weak inclination to found startups. • Failure is a social stigma.

4.

Fresh momentum for German innovation policy

This chapter will offer critical reflections on the current framework conditions and structures for disruptive innovation here in Germany, using international case studies as a point of reference. It will moreover identify promising elements and approaches from other states, and discuss the degree to which they can be transferred to the German context. Any look abroad in this area must include the U. S. Defense Advanced Research Projects Agency (DARPA). Even if this entity has a different set of objectives than Germany's Federal Agency for Disruptive Innovation (especially with regard to geopolitical strategies), and the basic military focus can certainly be viewed critically, it is worth taking a comparative look at its structures and instruments.

Israel is one of the world's most research-intensive countries, with a distinct high-tech orientation, a dynamic market for startups and a correspondingly robust system of financing (see Results Paper 4 in this series). Accordingly, the country has played a leading role in developing and promoting innovations, with the explicit goal of producing mission-oriented disruptive innovation.

Japan is one of the world's leading industrial countries. Japanese scientific authorities have regularly carried out technological and social forecast analyses (Delphi studies) since the 1970s (Cuhls 1998). Like Germany – though to an even greater extent – Japan faces the demographic problem of an aging society. In this context, it seems interesting to look at Japan, and at the programs there that address important societal, environmental and technological challenges. This is particularly true because the country expressly promotes and makes use of advanced technologies through its Society 5.0 vision, with the aim of readying Japanese society for future challenges in the area of digitalization and networking (see Results Paper 1 in this series for the analysis of Japan's development and innovation strategy).

The analysis is centered on the dimensions deemed crucial in producing disruptive innovation (Figure 1), as presented in chapter 2.

4.1 UNITED STATES

Promoting advanced technology through strong institutions

The ARPA was founded in 1958 as a research and development (R&D) agency inside the U.S. Department of Defense and renamed as DARPA in 1972. While the innovation organization had no notable predecessors on which to model itself at the time, it has acted in the intervening period as a public sector intermediary between the research and industrial communities. DARPA's research activities are aimed specifically at developing disruptive technological innovations able to fulfill missions associated with national objectives (see chapter 2). The focus is thus on radical innovation and technological development that goes beyond the merely incremental. The research expenditures entailed in this strategy are consequently associated with a very high level of risk; however, very substantial financial returns are also possible if project results can be successfully brought to market. DARPA plays a key role particularly in the development of information technologies, and has indeed been instrumental in numerous (disruptive) innovations in this area, including the internet, wireless data transmission, microprocessors, desktop computers, GPS technology, synthetic biology, computer simulations and self-driving automobiles.

Many of the technologies developed by DARPA have had far-reaching societal and economic impact, with the greatest effect – in line with the organization's self-declared goal – being to continually expand technical boundaries and convince people of the value of these developments. DARPA explicitly aims to have a disruptive and transformative effect on the status quo. Because innovations only occasionally arise by chance, more usually requiring active research efforts, DARPA sees itself as a so-called change agent (for more on this term, see Results Paper 1 in this series). In order to bring about innovation in established and leading economic sectors, the organization focuses primarily on the early stages of the innovation process – specifically on R&D activities and the development and demonstration of prototypes. These prototypes are then further developed, modified and ultimately brought to market by private sector actors (Bonvillian 2018).

DARPA's organizational structure is designed to be adaptable and responsive, in accordance with its areas of responsibility and stated objectives. As a consequence, the roles played by the established technology

offices have shifted repeatedly over the course of the entity's 60-year history. Today, DARPA has six technical offices with a total annual budget of about €3 billion, including the following:

- Biological Technologies Office
- Defense Sciences Office
- Information Innovation Office
- Microsystems Technology Office
- Strategic Technology Office
- Tactical Technology Office

Since DARPA is a funding organization, it does not have its own laboratories or research personnel. Rather, its core is made up of about 100 program managers, who are employees of the U.S. government. Rather than carrying out their own research projects, these individuals identify and support teams of researchers with the goal of developing disruptive technologies through research programs lasting up to five years (van Atta 2018). The program managers are given broad independence in managing their projects as long as they stay within their individual budgets, which typically amount to several tens of millions of euros. The managers are given time-limited employment contracts, with the resulting continuous rotation of personnel intended to make a steady contribution to innovation output.

Openness to new ideas, a culture of trust and the willingness to take risks are hallmarks of DARPA's success.

Because the research topics stem primarily from the program managers, each of whom advocates for his or her own specific ideas, DARPA can be viewed as a "bottom-up" organization. Projects are ultimately selected and assessed on the basis of their ability to address a technological or societal challenge. Openness to new ideas, trust as a prerequisite for autonomy, a willingness to take risks, and a tolerance for failure are key elements of the organization's innovation culture (DARPA 2016). During the implementation phase, the organization seeks to create networks between leading research teams. In addition, DARPA frequently brings small, innovative companies into contact with research institutions, so that the companies have access to potentially groundbreaking scientific findings, and researchers can see a specific path by which technologies can be brought to market. In recent years, the agency's unprecedented record of outstanding technological innovation has prompted the creation of other institutions following the DARPA model both inside and outside the United States, often with a similar structure but with different thematic priorities.[7] For example, the Advanced Research Projects Agency – Energy, founded in the United States in 2009, as well as Japan's innovation program for the promotion of disruptive technologies (ImPACT, see section 4.3), both borrow from the DARPA model (Bonvillian 2018; Cabinet Office 2017).

7 Further information on the DARPA model can be found in a recent study by the ifo Institute (Bunde et al. 2020).

LESSONS LEARNED

The following aspects of the U.S. DARPA agency are potentially transferable:

- (Long-term) funding opportunities: A long-term time horizon makes high-risk research and development efforts possible. As a result, numerous disruptive innovations with significant societal relevance have been produced in past years, particularly in the area of advanced technologies. Worth highlighting in this regard is the agency's significant involvement in the development of the internet, desktop computers and GPS technology.
- The establishment of a culture of innovation that supports the creation of new startups: In such an environment, failures are expected, and there is a widespread willingness to take risks that may not pay off. This tolerance for failure increases especially when a technological development is deemed to hold great potential for success, thus paving the way for disruptive innovation.

4.2 ISRAEL

Technological innovation as a goal of the private sector and the state

Innovation-policy measures have a long tradition in Israel. The Office of the Chief Scientist (OCS) was created in the late 1960s as an institution in what was then the Ministry of Industry and Trade, and tasked with supporting research and development projects among private companies. The adoption of the Law for the Promotion of Industrial Research and Development in 1985 helped shift the focus away from public sector and research institutions and toward support for private sector research and development (Trajtenberg 2000). This measure has since become known as the "Innovation Act," because it played a significant role in transforming the Israeli economy into a knowledge- and innovation-oriented market economy that is driven by the private sector and oriented strongly toward international markets. Since that time, Israel's economic growth has been dominated by high-tech industries in areas such as medical technology, electronics, and information and communications technology (ICT) (UNESCO 2016).

The OCS was transformed into the Israel Innovation Authority (IIA) in 2016; this entity can today be seen as the central institution in the Israeli innovation system. It directly advises government and parliamentary committees, and is responsible for planning and implementing the country's national innovation policy. Innovation is of paramount importance to Israel, deemed to be "the most valuable resource for the state of Israel, serving as a national asset crucial to economic prosperity" (IIA 2018).

The Global Competitiveness Report 2019 (World Economic Forum 2019) notes that on a comparative basis, Israel is also a global leader with regard to innovation activities. Its expenditure of 4.3 percent of GDP on research and development makes it the most R&D-intensive country in the world. In Germany and the European Union, the share of economic output invested in research and development is considerably lower, falling respectively at about 3 percent and 2 percent

(Eurostat 2020). In addition, Israel has a strong startup culture that is complemented by rapid growth in the number of innovative enterprises (World Economic Forum 2019) (see Results Paper 4 in this series).

The IIA places particular focus on the development of technological innovations, using a variety of mechanisms to do so. These measures are summarized in a five-year plan that defines objectives and tasks in the context of innovative activities. During the current period (2018 – 2022), one primary objective, for example, is to expand the country's dominance in high-tech industries, while increasing the economic importance of this sector. Similarly, the agency is tasked with increasing private sector competitiveness and productivity, while additionally addressing societal challenges. In 2018, the agency provided financing to about 1,500 individual projects, for a total funding volume of about €400 million, focused on the life sciences and advanced-technology-enabled product manufacturing. Organizationally, the IIA is divided into six departments with different areas of responsibility and separate annual budgets (IIA 2019):

- Technological Infrastructure, about €75 million
- Startup, about €100 million
- Growth, about €180 million
- Advanced Manufacturing, about €30 million
- Societal Challenges, about €20 million
- International Collaboration, about €25 million

These departments are intended to serve as a launch pad for technology projects, offering companies a variety of funding programs to assist in the implementation of innovative ideas. Israel's innovation policy is thus based on the idea of long-term cooperation between state institutions, private companies and research institutions. Due to the geographic proximity between the R&D centers and industrial locations, the significant concentration of human capital, and strong relationships of interdependence with international actors, the Israeli innovation system can be described as an open ecosystem. In this regard, the state plays a key role in supporting and further developing the innovation ecosystem (Dyduch and Olszewska 2018).

The state plays a central role in Israel's innovation ecosystem.

LESSONS LEARNED

The following aspects of Israel's production of mission-oriented disruptive innovations are potentially transferable.

- The openness of the innovation system and associated strong networks between actors: This factor is due in large part to the geographic proximity between actors, and the complexity of its geopolitical situation. This also includes the fact that the support instruments employed are continually adapted to reflect the changing requirements of innovative activities (IIA 2018). In Germany, by contrast, instruments and programs for promoting innovation are generally topic-specific, and are less flexible (e. g., the "KMU-innovativ" funding initiative).
- The explicit orientation toward societal challenges: In Israel, this has even taken the form of a dedicated department within the IIA. This serves as a useful model for the German innovation system, if the goal is to do more in the future to facilitate the solution of societal problems through innovation.

4.3 JAPAN

Program-based facilitation of disruptive innovations

In response to prolonged economic stagnation and the massive decline in competitiveness underway since the 1980s, the Japanese government set itself the goal of establishing a new framework for science and technology that would foster the expansion of innovative growth areas and breathe new life into Japan's innovation system. This involved a reform in recent years of the country's research, technology and innovation policy by the Council for Science, Technology and Innovation, which is under the leadership of the prime minister and his Cabinet Office. A key feature of this reform was the creation of the "Impulsing Paradigm Change through Disruptive Technologies" (ImPACT) program in 2013, though there are other programs aimed at fostering innovation. As a nationally prioritized program that is linked to the Society 5.0 innovation strategy (see Results Paper 1 of this series), ImPACT aims to produce disruptive innovations in tech through ambitious R&D spending and thus initiate economic and societal change (Cabinet Office 2017).

Part of the program involved a process that incorporated the views of stakeholders in science, business and politics in identifying the following key themes:

- Overcoming constraints on resources and innovation activities in traditional manufacturing sectors.
- Achieving an ecologically sound society and realizing innovative energy conservation.
- Applying smart technology for societal gain.
- Creating the world's most comfortable living environment in a society with a declining birth rate and an aging population.
- Minimizing the hazards of natural disasters.

As these themes determine how each R&D project is conceptualized, the process reflects a strong top-down dynamic. In addition, the topics are formulated broadly enough to enable a variety of approaches in technology and thereby nurture the generation of disruptive innovations (Aoki et al. 2014). In the existing

Japanese innovation system, where each institution draws on the R&D resources at its disposal, high-risk and thus high-impact research efforts of this kind have proved difficult to implement.

The ImPACT program is designed to meet precisely these requirements and create disruptive innovations by opening up R&D funding and incorporating promising technologies from within and outside the country. The focus of support is primarily directed at established companies, while SMEs attract less attention. This could prove problematic insofar as disruptive and radical innovations often come from new or non-established actors. Furthermore, internal cooperation as well as that between science and industry is often difficult, which creates the risk of developing isolated applications for which there are no corresponding fields of application on the market.

The ImPACT program has introduced into its organizational structure a program manager method similar to that seen in DARPA (see section 4.1), though this has yet to be applied in national projects. ImPACT program managers are not researchers, but rather producers who set high goals, select a team of top reputable researchers and conduct risky, effective R&D in order to bring about transformative change in industry and society. ImPACT's 16 program managers oversee an annual budget that totals nearly €500 million and which is distributed across a large number of R&D projects. However, this small circle of program managers underscores just how dependent the R&D projects are on the managers, which is in part at cross-purposes with ImPACT's claims to fostering openness. Support for the R&D programs introduced within the framework of ImPACT is provided in stages as depicted in Figure 4.

ImPACT's research priorities include photonics, information and communication technologies, analytical chemistry, medicine and molecular biology. This includes, for example, creating IT devices with long product life cycles, recycling radioactive waste through nuclear transmutation, developing high-resolution lasers and 3D imaging techniques or big-data platforms for predictive and preventive healthcare (Cabinet Office 2017). New mission-oriented policy and innovation approaches, on the other hand, have so far been less relevant in the ImPACT program and have drawn only indirect attention. The program aims primarily to provide visionary support for innovation by identifying and cultivating awareness of new ideas, which then heavily influences how funding is distributed.

ImPACT's ultimate goal is to make Japan the world's most innovation-friendly country with a thriving entrepreneurial spirit. Since these goals cannot be achieved by the program alone, successful R&D projects should serve as a model for future action models targeting the creation of disruptive innovations in other areas and sectors within Japan (Council for Science and Technology Policy 2014).

FIGURE 4
PROMOTION OF R&D PROJECTS IN JAPAN'S IMPACT PROGRAM

Determination of the issue to be resolved	• The Council for Science, Technology and Innovation defines issues to be addressed. • Program managers clarify the goals to achieve that are needed to bring about a change in industry and society.
Concepts for issue resolution	• Program managers propose ideas for creative R&D programs and remain apprised of the current state of affairs and trends in society and industry, also with regard to future commercialization.
Configuration of the R&D programs	• In order to realize their R&D concept, project managers put together a team of top researchers, independent of their area of expertise or institution. • Implementation systems are set up for R&D programs that include support measures initiated by project managers.
Management of R&D programs	• Project managers steer R&D programs toward achieving their agreed upon objectives. • As part of the process, researchers are encouraged to collaborate or compete with each other, and the programs continually adapt their activity in order to achieve the best possible results.
Development of R&D results	• To ensure that the R&D results lead to innovations, the project managers manage intellectual property issues and standardize the technologies involved. • The goal here is to ensure that the research results are implemented in society and are commercialized by emerging businesses both within and external to the R&D programs.

Source: Own representation (based on Cabinet Office 2017)

LESSONS LEARNED

The following aspects of Japan's ImPACT program are potentially transferable:

- Flexibility in support for projects: Each program manager assembles an independent team that researches and develops promising technologies that are relevant to industry and society. They do not dictate specific themes to teams.
- Gearing project support to market or demand needs, for example in the area of elderly care, where social innovations and innovative technologies can help alleviate the burden of intensive care tasks.

5.

Lessons learned

In the following discussion, we will seek to shed more light on the degree to which the results of our research into international good practices can be feasibly transferred to Germany. In doing so, we will structure the section around the dimensions described in Figure 1 (page 21).

Research and innovation support

With regard to promoting research and innovation, Germany faces the challenge of designing support measures so they no longer break off at the point of market introduction. EU-level restrictions on providing state aid limit flexibility in this regard. Nonetheless, all three countries mentioned above can be regarded as good examples in this area, as they explicitly address users in their strategies. In addition, Germany's innovation-promotion system – along with the support provided for technology transfer, and to new startups as a means of bringing innovations to market – still features significant gaps (the "valley of death"). Although novel funding and technology-transfer instruments are available, these are not applied flexibly enough when it comes to new knowledge. A crucial disadvantage is the fact that high-risk projects in particular are unable to obtain support. This hampers the development of disruptive innovations with societal relevance, as these are by definition associated with a significant level of risk. Here, DARPA can be regarded as a model worthy of emulation, as it specifically supports risky projects as long as a high level of potential societal benefit is apparent.

Research system

As currently constituted, Germany's research system is not designed to produce mission-oriented disruptive innovations. This is partially due to the fact that scientists' conceptual frameworks and career paths remain strongly shaped by and focused on their own scientific fields. The transdisciplinary mode of thought necessary to generate disruptive innovation thus receives insufficient support. In addition, scientific publications are still seen as the most essential form of output within the university sphere – much more so than high-risk research or engagement with speculative ideas. Along with the temporary contracts frequently used for university research staffers, this has an inhibiting effect on disruptive innovation.

Even if the project-manager methodology used by DARPA in the United States or by the ImPACT program in Japan provides for research projects with durations of only about five years, and thus does not

sufficiently account for the time horizon needed to generate disruptive innovations (usually more than 10 years), this model is a good one, as it brings together researchers working on the cutting edge in a wide variety of disciplines. Linking ideas from across disciplines would promote the production of disruptive innovations, thanks to the creation of stronger networks between the actors. However, releasing researchers for periods of work on high-risk research projects must be compensated accordingly.

Education and training

Like the research system, the vocational education and training system in Germany remains focused on specific disciplines and/or technologies. Building on the strengths of the dual system, innovations could be put directly into practice through the use of cross-disciplinary learning groups – including a stronger degree of internationalization, following the Israeli model (thus enabling students to gain a broader perspective).

Cooperation and technology transfer

In addition to the measures discussed above, cooperation and technology-transfer efforts should take place not simply between research institutions and the private sector, but also in a cross-disciplinary way. Following the DARPA model, research teams could be created with the specific goal of including well-known scientists from a variety of different fields. At the same time, as a condition of such work, innovation processes must be kept open (see Results Paper 2 in this series), because the views of other actors, for example from civil society, represent a valuable contribution to the success of (disruptive) innovations. While Israeli policymakers have for years recognized innovation as a key element of economic success and in the solution of societal problems, and have facilitated knowledge and technology transfer with appropriate support mechanisms, much remains to be done in this regard in Germany.

Market/international engagement

Especially in the area of new consumer-facing digital products and services, Germany's innovation output is minimal in comparison to that stemming from the key economic sectors of mechanical and automotive engineering, electrical engineering, chemical engineering and medical technology. This is problematic, as it means there are few digitalization world-market leaders located here. As future disruptive innovations can be expected to emerge disproportionately in this area, German innovation promotion should focus more strongly on information and communications technologies, as well as on other high-tech fields. Despite a high degree of international scientific and technological cooperation in Germany, the potential offered by cross-national collaboration is not yet being fully exploited. Israel's IIA sets the standard in this regard: Its strategies incorporate both the local and the international innovation ecosystems, by providing international markets with developed technologies and by treating Israel as a base for international entrepreneurship.

However, national missions remain a key focus of efforts to promote disruptive innovation worldwide. This typically involves prioritizing thematic areas tied closely to national-state objectives (e. g., in the area of security or national technological competitiveness), with national research and innovation activities seen as the primary means of reaching these goals. The international dimension usually comes from opening up new markets, rather than from cross-national cooperation.

This is true of Germany as well, where the theme of disruptive innovation is quite frequently discussed with reference to other countries' innovation systems – but implementation is in practice intended to secure and enhance national scientific and technological competitiveness. Recently, France and Germany have moved toward internationalizing the promotion of disruptive innovation with efforts to establish an agile agency for disruptive innovation, the Joint European Disruptive Initiative (JEDI). If realized, this agency is intended to be jointly managed by public agencies and actors in the innovation system, and will focus on financing technological challenges for the solution of societal problems that are too risky or entail a time horizon too prolonged for private sector investors (Loesekrug-Pietri 2018). However, these ideas for a Franco-German disruptive-innovation agency are not currently being pursued further.

Sociopolitical and cultural context

Efforts to generate disruptive innovation in Germany are additionally impeded by the fact that the country's population is relatively risk-averse. This is reflected in the low startup-founding rate in international comparison. This trend is reinforced by the fact that entrepreneurial failure is seen as a social stigma, unlike in the United States, where taking an entrepreneurial risk is respected even in the event of failure.

Widespread risk aversion in Germany limits the growth of disruptive innovation in the country.

6.

Conclusions and recommendations

The international examples show that disruptive innovation can be successfully promoted in a variety of different ways. Disruptive innovations are not the only avenue for developing solutions to global problems, but they can make an essential contribution.

Based on the analysis of the situation in Germany and the international examples, we can derive the following conclusions and recommendations for promoting disruptive innovation here. The items are once again structured along the dimensions identified in Figure 1.

Research and innovation support

- Hold innovation competitions with ambitious goals, and which entail continuing support for the winning projects.
- Provide support with a long-term time perspective, as significant technological leaps typically require 12 to 15 years to realize major financial returns even if they are successful.
- Provide thematically open support measures that define objectives on the basis of national strategies (e.g., with reference to missions or a contribution to the SDGs), but which do not mandate a specific solution (see also Results Paper 1 in this series).
- Provide support to high-risk ideas and projects (that is, with a probability of failure greater than 50%), as it is bold ideas in particular that can produce innovations with great potential.
- Develop and offer targeted solutions to bridge the "valley of death."
- Link innovation support to promising approaches such as open innovation (e.g., in the form of innovation and testing spaces, or regulatory sandboxes), user innovation and collaborative innovation (see also Results Paper 2 in this series).

- Involve high-profile figures (researchers, visionaries, motivators), in part by giving them responsibility for innovation projects with disruptive potential.

- Consider additional evaluation criteria for project support (e. g., market acceptance; societal acceptance; demand-side system and market failures; inertial forces such as learning costs, path dependencies, infrastructure or regulation).

- Strengthen the role of the state as a customer, for example through new public procurement rules that take innovation- and technology-policy criteria into account as well as the price. In this way, policy could enable disruption through the use of public procurement incentives (see also Results Paper 1 in this series).

- Utilize the scope of administrative discretion granted by existing laws more proactively for innovation projects and include more experimental clauses in laws relevant to innovation activities (referencing both the creative process and the process of bringing products or services to market).

- Promote and develop the capability and willingness to innovate within the public sector.

Research system

- Create incentives for inter- and transdisciplinary research (within the research system and beyond), and incorporate activities of this nature into research organizations' evaluation systems.

- Minimize the use of time-limited contracts in the scientific research system, so as to increase the appeal of (radical) research and development projects as professional activities; at the same time, expand funding periods to encompass a long-term time horizon (>3 years), so as to account for the time needed to develop disruptive innovations.

Education and training

- Integrate transdisciplinary working methods into educational and training settings, so as to promote the new ways of thinking essential to the development of disruptive innovations.

- Ensure that training and qualification programs do a better job of encouraging mixing across professional disciplines.

Cooperation and technology transfer

- Develop new cooperation programs and intensify existing cooperative efforts. This should entail bringing private sector and research actors together; however, actors from both of these areas should also be brought together with new groups of actors (e. g., from civil society, user and makerspace groups, startups, and venture-capital donors – see Results Paper 4 in this series).

Market/international engagement

- Think about disruptive innovation on a European and global basis, by establishing a local presence in global innovation centers, coordinating with European initiatives (European Innovation Council, JEDI initiative) and taking an open approach to disruptive-innovation initiatives with partners from other countries.

Sociopolitical framework

- Increase the significance that society attributes to innovation and innovative minds; work (e. g., in kindergartens, schools and universities) to establish a societal appreciation for risk and failure as consequences of positive, courageous behavior.

- Create and develop infrastructures that facilitate experimentation and innovative activities, with strong involvement by civil society (e. g., creative laboratories, experimental workshops, but also laboratories and workshops enabling testing procedures and the development and construction of prototypes).

The agency model, like that of DARPA in the United States or SprinD in Germany, is one option for promoting disruptive innovation. However, a number of additional factors, such as long-term funding opportunities; open-innovation processes and systems; flexible program design; and a culture in which daring, risk and efforts to found startups are an accepted part of society, also help generate disruptive innovation and disruptive innovations. In doing so, they also help to solve overall societal problems at the global level (climate change, diseases, energy supply, etc.). It seems that Germany's policymakers and population have today recognized the value of disruptive innovation as a means of meeting the challenges of our time. However, there remains much to be done in terms of establishing policy frameworks that foster innovation with efficiency. This is where we need to take stronger action in the future.

Germany also needs to improve the environment for fostering disruptive innovation.

7. APPENDIX

7.1

Global research on good practices – our interview partners

INSTITUTION/ORGANIZATION	INTERVIEW PARTNER
1E9 (Munich)	Herbert Mangesius
acatech – National Academy of Science and Engineering (Munich)	Dr. Jan Henning Behrens
Bertelsmann Foundation (Washington)	Irene Braam
Briter Bridges (London)	Dario Giuliani
Bundesverband Deutsche Startups e. V. (Berlin)	Christoph J. Stresing
Business Finland (Helsinki)	Pekka Sivonen
Canadian Institute for Advances Research (CIFAR) (Toronto)	Rebecca Finlay
Center for Data Innovation (Brussels)	Eline Chivot
Centre for Social Innovation (Toronto)	Raissa Espiritu
Co-Lab Sweden / Förnyelselabbet (Stockholm)	Pia McAleenan
Digital Catapult (London)	Brian MacAulay Cordelia O'Connell Jessica Rushworth
Ecosia (Berlin)	Dr. Wolfgang Oels
European Commission – Directorate-General Research and Innovation (RTD) (Brussels)	Maximilian Steiert Renzo Tomellini Isabel Vogler
Federal Ministry for Economic Affairs and Energy (BMWi) (Berlin)	Thomas Jarzombek, MdB
Federal Ministry of Education and Research (BMBF) (Berlin)	Engelbert Beyer Dr. Gisela Philipsenburg
Fonds de Recherche du Québec (FGR) (Montreal)	Julie Dirwimmer Sophie Gauthier-Clerc Benoit Sévigny
Founders Foundation (Bielefeld)	Sebastian Borek
German Chamber of Commerce and Industry in Japan (AHK Japan) (Tokyo)	Dr. Lucas Witoslawski
German Consulate General Montreal	Dr. Markus Lang
German Institute for Japanese Studies (DIJ) (Tokyo)	Dr. Susanne Brucksch Prof. Dr. Franz Waldenberger

INSTITUTION/ORGANIZATION	INTERVIEW PARTNER
German Research Center for Artificial Intelligence (DFKI) (Berlin)	Julia Gundlach
Innosuisse (Bern)	Eliane Kersten Marc Pauchard
Innovate UK – UK Research and Innovation (UKRI) (London)	Dan Hodges
Innovation Policy Lab – Munk School of Global Affairs and Public Policy, University of Toronto	Travis Southin Prof. David Wolfe, PhD
Institute for Competitiveness (I-Com) (Brussels)	Mattia Ceracchi
Internet Economy Foundation (IE.F) (Berlin)	Amelie Drünkler Clark Parsons
Japan Science and Technology Agency (JST) (Kawaguchi)	Prof. Hiroshi Nagano Tomoko Sawada
Kienbaum Consultants International (Cologne)	Stephan Grabmeier
Laboratorio de Gobierno (Santiago de Chile)	Roman Yosif
LabX – Laboratório de Experimentação da Administração Pública (Lisbon)	Bruno Monteiro
Lindholmen Science Park (Göteborg)	Tord Hermansson
MaRS Discovery District (Toronto)	Matthias Oschinski, PhD Dwayne Simms
Max Planck Institute for Innovation and Competition (Munich)	Prof. Dietmar Harhoff, PhD
Ministère de l'Économie et de l'Innovation Québec (Montreal)	Inji Yaghmour
Ministry of Economic Affairs, Agriculture & Innovation (The Hague)	Luuk Klomp
Ministry of Economic Affairs and Climate Policy (The Hague)	Koen de Pater
Ministry of Economic Affairs and Employment of Finland (Helsinki)	Anita Silanterä Kirsti Vilén
Ministry of Economic Development, Job Creation and Trade Ontario (Toronto)	Vasu Daggupaty Alex Lee Ernst Lueger

INSTITUTION/ORGANIZATION	INTERVIEW PARTNER
Mitacs (Montreal)	Coryell Boffy
Montreal Institute for Learning Algorithms (Mila) (Montreal)	Stéphane Létourneau
Nesta (London)	Peter Baeck Albert Bravo-Biosca, PhD Marieke Goettsch Eva Grobbink
Ontario Digital Service (Toronto)	Waqas (Wes) Iqbal
Organisation for Economic Co-operation and Development (OECD) (Paris)	Caroline Paunov
PHINEO gAG (Berlin)	Dr. Andreas Rickert
Prototype Fund – Open Knowledge Foundation Deutschland e. V. (Berlin)	Adriana Groh
Reinhard Mohn Institute for Corporate Management, University Witten/Herdecke	Prof. Dr. Guido Möllering
Roland Berger GmbH (Berlin)	Dr. Julia Oppermann
RWTH Aachen, Center Smart Services (Aachen)	Benedikt Moser
SDGx (Berlin)	Christian Walter
Sitra (Helsinki)	Timo Hämäläinen, PhD Markus Kalliola Paula Laine
Staatslabor (Bern)	Alenka Bonnard
Startup Genome (Berlin)	Marc Penzel
Swedish Incubators & Science Parks (Stockholm)	Kajsa Hedberg
UnternehmerTUM (Munich)	Johannes von Borries
Vector Institute (Toronto)	Cameron Schuler
Vinnova (Stockholm)	Göran Marklund Judit Wefer, PhD
ZEW – Leibniz Centre for European Economic Research (Mannheim)	Dr. Georg Licht

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Glossary

ARPA	Advanced Research Projects Agency (U.S. innovation agency 1958–1972)
DARPA	Defense Advanced Research Projects Agency (U.S. innovation agency, renamed in 1972)
ICT	Information and communication technology
IIA	Israel Innovation Authority
ImPACT	Impulsing Paradigm Change through Disruptive Technologies Program (Japan)
IT	Information technology
JEDI	Joint European Disruptive Initiative (Franco-German initiative promoting the establishment of a European innovation agency)
OCS	Office of the Chief Scientist (Unit within Israel's Ministry of Energy)
R&D	Research and development
SDG	Sustainable Development Goals of the United Nations
Valley of Death	Funding gap
VC	Venture Capital

7.4

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CONTACT

Bertelsmann Stiftung
Carl-Bertelsmann-Straße 256
33311 Gütersloh
Germany
Phone: +49 5241 81-0
www.bertelsmann-stiftung.de

Dr. Daniel Schraad-Tischler | Director
Program Shaping Sustainable Economies
Phone: +49 5241 81-81240
E-Mail: daniel.schraad-tischler@bertelsmann-stiftung.de

Dr. Jan C. Breitinger | Project Manager
Program Shaping Sustainable Economies
Phone: +49 5241 81-81328
E-Mail: jan.breitinger@bertelsmann-stiftung.de

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Bertelsmann Stiftung
Carl-Bertelsmann-Straße 256
33311 Gütersloh
Germany
Phone: +49 5241 81-0
www.bertelsmann-stiftung.de

Responsible for content
Dr. Daniel Schraad-Tischler | Dr. Jan C. Breitinger

Authors
Hendrik Hansmeier
Prof. Dr. Knut Koschatzky

Scientific analysis
Fraunhofer-Institut für System- und Innovationsforschung ISI,
www.isi.fraunhofer.de

Contribution
Lea-Melissa Vehling
Gabriel Zech

German language editing
Heike Herrberg

Translation
Barbara Serfozo

Graphic design
FORMBA Editorial & Design, www.formba.de

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Address | Contact

Bertelsmann Stiftung
Carl-Bertelsmann-Straße 256
33311 Gütersloh
Germany
Phone: +49 5241 81-0

www.bertelsmann-stiftung.de/fosteringinnovation

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