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Governmental Support Options for the Technology Transfer of Deep Tech Innovations

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***Abstract* – In recent years, systemic and society-changing technological innovations (Deep Tech or DT innovations) have emerged primarily in the USA and Asia, while Europe is technologically dependent in many application fields. The development of DT is characterised by high financial capital needs. Additionally, intellectual property (IP) management plays a major role. To reduce the technological dependency for many areas in Europe, an adjustment of the government's role as an actor in the innovation system appears beneficial. Targeted measures can improve the development and transfer of DT and, thus, contribute to securing long-term competitiveness of European nations. The aim of this contribution is therefore to identify support options within the technology transfer of DT innovations by conducting a structured literature analysis. In total, 27 applicable options are identified and structured into derived fields of action within innovation systems.**

***Keywords* – Deep tech, entrepreneurial state, technological dependency, technology transfer.**

I. Introduction

Systemic and society-changing technological innovations (Deep Tech / DT) have emerged in recent years primarily in the USA and the Asian region [1], while Europe has become technologically dependent in many areas [2]. However, the successful development of DT innovations is an important building block for securing societal prosperity in Europe in the future [3], [4].

The room for optimization of DT initiatives in Europe and especially Germany – as one of the strongest economies in the European Union – can be explained by a lack of success in transferring research results to industry [5], [6]. Initially, the German research landscape with its differentiated science and education system offers a fruitful baseline for the development of DT innovations [6]. The reasons for the transfer challenges of technologies are manifold. In Germany, the transfer is predominantly supported by means of direct financial funding, instead of applying an extensive mixture of political instruments to the funding as it is the case in other countries. This observation is supported by a study of the *Expert Commission on Research and Innovation*. Their data show that, compared to most of other industrialized nations, Germany only provides direct support for industrial research and development (R&D), instead of additionally promoting R&D through indirect support measures [7].

The transfer of DT in particular poses an additional challenge [5] as it has high financial requirements over a long period of time and is also often associated with bureaucratic and legal hurdles [8]. Since the chances of failure for such technological developments are high, it leads to a considerable risk which the actors involved in a transfer process are often unwilling or even unable to take. These circumstances are compounded by the fact that the development of disruptive technological innovations often fails due to institutional characteristics (e.g., general risk aversion, lack of venture capital) within the German innovation system [1], [9].

To improve this situation, a fundamental adjustment of the government's role as an actor in the DT innovation system is necessary. In the future, the government must actively support in the innovation system to comprehensively promote the transfer with a wide variety of measures to make a significant contribution to the creation of globally competitive companies. International examples show that this active approach can be successful: in the USA, for example, the *DARPA*, which is affiliated with the *Department of Defense*, strongly acts as a public purchaser. The agency awards major contracts for technological innovations at early stages of development, deliberately taking the risk for such developments to fail. Secured financing and sales of the later product accelerate the development process and significantly increase the chances of sustainable success [10], [11]. Following this approach, society-relevant innovations are repeatedly created, such as the *Global Positioning System (GPS)*, the world wide web or the *Speech Interpretation and Recognition Interface (SIRI)* [12].

The example shows that societies can highly benefit from a successful transfer of DT innovations. Beyond the mere use of an isolated innovation, a successful technology transfer forms the basis for growth and prosperity [13]. It also strengthens economic competitiveness and creates social stability. The development and exploitation of DT thus creates new jobs and potentially increases the quality of life [5]. In Europe, it can also contribute to the return of technological sovereignty in many technological fields, which is of particular interest given the current geopolitical situation [14].

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To sum up, the sustainable success of technology transfer processes – especially for DT innovations – is too little, although various initiatives and measures are discussed and initiated. From a practice-oriented perspective and to ensure such sustainable success, there is thus a need for a systematic derivation of comprehensive and multidimensional support measures from the government for the transfer of DT from research to industry fitting the particular innovation system needs. For this reason, the goal of this paper is to identify diverse governmental support options for the technology transfer of DT innovations, plus, beforehand, to derive the most important barriers to the transfer of DT within innovation systems.

To achieve this goal within the paper, fundamentals relevant to the topic are presented in Section II. Afterwards, existing approaches within the applicable research areas – DT, technology transfer, governments as actors within the innovation system – are discussed and evaluated to refine the theoretical relevance in Section III. In Section IV, the underlying methodology for the systematic literature research is presented. Afterwards, the results are outlined in Section V. Finally, a conclusion and critical reflection of the approach and results are given in Section VI.

II. Fundamentals

To form a consistent understanding within this paper, definitions of *Deep Tech, Technology Transfer* as well as vital fundamentals of *governments as actors within innovation systems* are provided. These fundamentals will help conduct a focused literature review in Section III and function as a baseline for the derivation of results in Section V.

A. Deep Tech

DT describes knowledge-based technologies that have the potential to radically change existing markets or to create entirely new markets [15]–[19]. Areas in which DT predominantly emerges are healthcare, agriculture, mobility, energy and manufacturing [4], [5], [20]. The development of DT from research to market maturity requires an above-average consumption of resources, especially financially, as well as a high investment of time [16]–[18], [21], [22]. Due to these characteristics, and a high degree of novelty as well as a high technological complexity, a huge technological and commercial risk is inherent when developing DT [17], [18], [20]. However, successfully developed DT potentially exhibits a significant advantage over existing technologies to be substituted or complemented [8], [16]–[18], [22], [23]. DT addresses the substantial societal and environmental problems of the 21st century and is, thus, of significant importance and interest for societies [4], [24].

Due to the high complexity of DT, well-connected ecosystems are required for successful development and deployment [17], [25]. At the same time, the successful development of DT within these ecosystems generates spillover effects that positively influence and drive the economic development of entire regions [5]. Furthermore, scholars emphasize that due to the high degree of novelty, regulatory uncertainties regarding the development and application of DT often exist [18], [24]. An example is the DT startup Seaborg Technologies, which developed a novel nuclear reactor to which existing regulations did not apply [24]. Another characteristic of DT is its interdisciplinary nature [5], [24]. Gourevitch et al. state that over 96 % of the DT they studied was based on two or more technological foundations [5], [24]. Technologies frequently used in DT innovations include combinations of, e.g., artificial intelligence and machine learning, materials engineering, nanotechnology, and biotechnology [5].

Different authors disagree on the type of resources for DT: while according to some authors it includes digital developments, such as standalone AI-based software without hardware interaction [23], [24]. Schuh et al. argue that physical artifacts are necessarily included [15]. In this context, Schuh et al. note that the production of physical products requires the existence of a suitable infrastructure, which is associated with a considerable expenditure of resources [15].

Combining the contributions of Schuh et al., Kilic, and De La Tour et al. within this paper, DT is defined as follows [15], [17], [18]:

Deep Tech represents innovative technologies of (cyber-) physical nature that are characterized by long development times, high capital requirements, as well as high market and technology uncertainty, and addresses fundamental societal as well as environmental challenges. Deep Tech exhibits significant technological advancement compared to established technologies and have the potential to radically change existing markets or create completely new ones.

B. Technology Transfer

The term "technology transfer" is composed of the terms technology and transfer. Transfer is a Latin compound term (*Latin translation*: *trans* – across a border; *ferre* – to carry) that can be translated as transmission [26]–[28]. In the context of technology transfer, transfer thus encompasses technologies. In German-speaking countries, the term has been used since the mid-1970s, particularly in politics as well as in economics and engineering [29]–[31]. At that time, the term was primarily used to describe the export of technologies and technological assistance provided by industrialized nations to developing countries for the purpose of development aid [29], [31], [32]. Today, the term is predominantly used to describe the transfer of technologies from research to industry or business with the goal to innovate [30], [33], [34].

Following this focus, Reinhard and Schmalholz define technology transfer as "the planned transfer of scientific and technological knowledge between individuals and organizations for the purpose of innovation" [35]. Corsten sees technology transfer as "(...) a planned, time-limited and voluntary process of transferring a technology (...)" [36]. He further emphasizes that transfer takes place to reduce the difference between the potential (representing all possible applications of a technology) and current degree of use of a technology. Fichtel frames technology transfer as "the transfer of technological knowledge for the economic solution of technical problems from a technology provider to a technology taker [...], where this transfer takes place between two economically and legally independent organizations" [29]. The author further assumes that the acquired technology is to be used to increase the competitiveness on the side of the technology receiver. Walter describes technology transfer similarly to Corsten as "value-oriented, planned and time-limited exchange processes between organizations, which have the transfer of technologies from their scientific basis into economic applications as their goal" [37]. Another dominant and, especially in the Anglo-American literature, frequently cited definition of technology transfer comes from Brooks: "The process by which science and technology are diffused throughout human activity. Wherever systematic rational knowledge developed by one group or institution is embodied in a way of doing things by other institutions or groups, we have technology transfer" [38]. All definitions presented have in common that the transfer of technology is not the actual goal, but that the transfer is rather to be understood as a tool to bring a technology into an economic application or an industrialization process, i.e., to convert it into an innovation.

In this paper, technology transfer is defined according to the definitions of Corsten, Fichtel and Walter:

Technology transfer is the planned, time-limited and voluntary process of transferring a technology from a technology provider (explicitly science) to a technology taker (explicitly industry). Technology means a technical artifact together with the associated knowledge. The transfer does not take place as an end in itself but serves the overriding goal of producing technological innovations.

C. Governments as Actor within Innovation Systems

The term "state" (hereinafter also referred to as "government") is constantly used in everyday life and an approximate understanding commonly exists, but the exact understanding is difficult to specify or define. According to Isensee, this effect is due to the complexity and the spatio-temporal mutability of state phenomena [39]. This means that the concept of a state focuses on different areas depending on the aspect considered or the perspective on the concept, and that these ways of perspective have changed over the past centuries. For example, different views or perspectives on the state in law, economics, or government and administration exist [40]. Governmental and administrative theory sees the state as the sum of individual institutions, such as the parliament, the government, the administration, the judiciary, and more. The theory of the state, on the other hand, sees the state as an institution in its own right, distinguished from other social institutions by specific structural features [41]. For a detailed discussion of different conceptions of the state, it is referred to Voigt, who discusses the different perspectives in detail [40].

The existence of a state is associated with multiple functions and desires since the institution of the state serves as a representative of its society and must act in its interests. The functions, in turn, vary with their underlying social theories [41]. Basically, these functions can be summarised as (1) survival of society, (2) economic functioning, (3) social functioning, and (4) cultural functioning. More concrete, the state is responsible for external protection, internal peacekeeping and safeguarding of the natural foundations of life. From an economic point of view, the state must take care of the property system, the monetary system and the market system. In the social sphere, the state ensures that social rights are guaranteed, and that social justice prevails. In addition, ensuring general education for all citizens and promoting basic research fall within the remit of the state [41].

From a technology transfer perspective, the state can be situated within the concept of an innovation system. This system was first introduced by Lundvall in the 1990s and is since then widely established in the scientific literature [42], [43]. The concept assumes that innovations emerge within an interactive and feedback-driven process, whereby a wide variety of actors meet and cooperate in different phases of the innovation process [42]. According to Edquist, summarising this filed in his definition, innovation systems are characterised by "(...) all important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion and use of innovations" [44]. He also points out that the innovation system consists of two components: the actors of the innovation system and the relationships between the actors [44].

An established model of a national innovation system, wherein governments play a highly relevant role, comes from Kuhlmann and Arnold [45]. This model is often used as an analytical framework in scientific literature and focuses on the actors of the *industrial, education and research system*, as well as *intermediaries* between these system elements. They are linked by bilateral relationships. Additionally, the *political system* plays a central role. The *political system* influences the *education and research system*, the relations between research and industry as well as the *framework conditions* and the *infrastructure* of an innovation system. According to Kuhlmann and Arnold, the element *demand* is part of the innovation system and represents its most important growth driver, comprising both consumer demand and producer demand for intermediate products. The *demand* is bilaterally related to the *education and research system* and the *industrial system*. Fig. 1 illustrates this concept of a national innovation system taking into account various actors.

Within the present paper, the possibilities of a stronger influence of the state as an actor of the innovation system into technology transfer processes are examined. Classically, the legitimization of the state to intervene in market and industry processes and respective innovation activities is founded in the phenomenon of *market failure* [12], [46]–[49]. According to this view, the market alone does not sufficiently invest in the generation of knowledge, since knowledge is often exploited by free riders due to its public nature, and actors in the market are additionally deterred by the high degree of uncertainty about the commercialization prospects of research results [50]. This reasoning is based on a linear understanding of the innovation model, assuming that new knowledge generated in basic research is the most important source of innovation [51]. Therefore, the market failure argument predominantly considers the pre-competitive and non-market stages of the innovation process. Although the understanding of the innovation process has changed fundamentally, and systemic failures can occur at various points in the innovation system and at any time along the creation process [52], the theory of market failure is still frequently used today to justify government intervention in the innovation process [46].

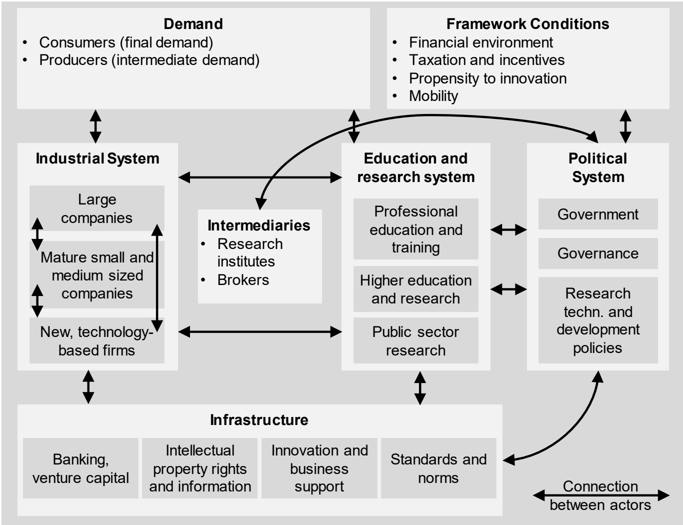

Fig. 1. National innovation system by Kuhlmann and Arnold [45].

Instruments of such government intervention or innovation policy can be systematized according to various criteria. In the following, the approach from Gerybadze originating from innovation research is exemplarily described. A system is presented that is explicitly attached to innovation policy and distinguishes between instruments that are geared to the supply side, those that are geared to the demand side, those that aim to create conditions conducive to innovation, and those that aim to influence networks and clusters, i.e., the relationships between actors in the innovation system. Supply-sided instruments are among the oldest instruments of innovation policy and are aimed at creating an improved infrastructure in public basic research as well as reducing risks in this area. Thus, they follow the technology-push paradigm and are still the focus of innovation promotion today. These instruments can be further subdivided into direct, indirect-specific and indirect support measures [53].

In contrast, demand-sided instruments attempt to cause a so-called demand-pull or market-pull. These instruments include government procurement, in which government institutions cause a large part of the (initial) market demand, thereby lowering the development risk of technologies and products and securing financing. Instruments that influence the innovation process via political and regulatory frameworks include market regulation measures, environmental technology and product safety and liability. In addition, state institutions play a central role in the field of standardization. The state can shape patent law and patent validity in a way that promotes innovation and can also decisively influence the innovation process through tax measures. The last important framework condition that can be influenced by the state are financing measures for startups, such as the provision of venture capital or loans [53].

It becomes obvious that the before-mentioned innovation policy instruments correspond to the characteristics of infrastructure and legal framework conditions within innovation systems according to Kuhlmann and Arnold [45]. Therefore, a combination is used to derive and structure the result within Section V.

As these explanations show, there is a plethora of innovation policy instruments that take effect at different levels of the innovation system and influence the actors and their relationships with one another in a wide variety. Nevertheless, the innovation system in Germany is supported in a very one-sided way, since the emergence and diffusion of innovations is supported almost exclusively by means of direct financial supply-side support [53]. Therefore, there are many opportunities to implement the untapped potentials of innovation policy in the German innovation system in the future. After these explanations, a definition of the state in the sense of the present work is formulated.

The state (i.e., governmental system) is seen as a controlling element of the innovation system, which has the power to intervene in it and to shape it. The goal of this intervention is to improve the innovation capability of the system to promote the emergence and diffusion of innovations and thus to secure long-term prosperity and technological sovereignty.

III. Literature Review

In this section, existing approaches within the context of governmental support for DT transfer from research to industry are reviewed and critically evaluated. For this purpose, the fundamentals defined above are used. Therefore, criteria for evaluating the approaches are set up first to enable a transparent qualitative assessment. This is followed by an analysis and critical appraisal of relevant approaches; before finally summarising, an evaluation is undertaken and the literature deficit and need for action within this paper are derived. As a result, the scientific relevance of this paper is shown.

A. Derivation of Evaluation Criteria

To ensure a focused evaluation of the existing theoretical approaches, evaluation criteria are divided into the superordinate categories of object area and target area. The object area includes criteria that serve to describe the object of analysis of the present work: the focus lies on DT or characteristic technological features of DT. These will be instrumentalized in the course of the work for further elaborations (Evaluation criterion I: *Consideration of DT characteristics for further analysis*). The approach considers inter-organisational technology transfer from research to industry and focuses on transfer barriers (Evaluation criterion II: *Consideration of technology transfer with a focus on transfer barriers*). Additionally, the approach takes the concept of innovation systems into account, focusing on the role of governments within transfer processes (Evaluation criterion III: *Consideration of the role of the state in the innovation system*).

Criteria of the target area, on the other hand, serve to examine the existing approaches to the extent to which they help to answer the research questions raised in this paper: The approach aims to identify technology transfer support options that can be used by governmental players (Evaluation criterion IV: *Determination of transfer support options*). Plus, the approach has the target to present a way to evaluate policy instruments according to different criteria or to structure them (Evaluation criterion V: *Evaluating and structuring governmental instruments within innovation support*). Finally, this contribution aims to introduce a systematic of the state's fields of action and establish a link between transfer barriers and support options (Evaluation criterion VI: *Derivation of state fields of action and linking transfer barriers and support options*).

B. Conduction of the Literature Review

Overall, 14 approaches from the scientific fields of DT, technology transfer and governments within the innovation system were identified as relevant and analysed based on the evaluation criteria presented. The results of the analysis are illustrated in Fig. 2. Within this paper, the results of four approaches are exemplary presented in detail sorted based on their year of publication:

Weyant 2011 – Accelerating the Development and Diffusion of New Energy Technologies: Beyond the "Valley of Death".

The aim of Weyant's paper is to provide a mixture of different policy instruments to promote climate-friendly technologies, taking into account both economic and political factors. In particular, the author addresses the gap between research and industry and argues that intervention is required due to market failures. First, the author lists reasons for governmental intervention to reduce greenhouse gas emissions. Further possible solutions and risks are presented and specified in subsequent sections. Finally, a recommendation for action is given regarding possible next steps and the design of support through the government [54].

The work deals with a specific type of DT, the characteristics of which will not be revisited for further elaboration in his work. Weyant analyses the transfer of technologies from research to industry and identifies some barriers to this transfer. However, these barriers are technology-specific and, thus, do not have a generally valid character. In addition, the presentation of the barriers is neither systematic nor sufficiently comprehensive. Although some support options are provided within the scope of the scientific elaboration, the role of the state or its fields of action in the innovation system are not explicitly addressed. The identified support options are assessed in terms of their impact and their risks, but no systematic structuring of the support options is conducted.

Wieczorek and Hekkert 2012 – Systemic Instruments for Systemic Innovation Problems: A Framework for Policy Makers and Innovation Scholars.

The publication of Wieczorek and Hekkert aims to develop and provide a framework that enables political actors to use innovation policy instruments in a targeted manner. The focus lies on systemic instruments that act on the central processes within the innovation system and influence them positively. To develop the approach, first, the individual structural elements of an innovation system are discussed. This is followed by a presentation of the functions of innovation systems, which are linked to the previously discussed structural elements. Afterwards, systemic problems of the innovation system are presented and then linked to systemic policy instruments. The result is a procedure in which the existing problems of an innovation system are first identified followed by the identification of political instruments which can positively influence these problems [55].

DT is not discussed in the publication, nor is technology transfer explicitly addressed. The role of the state is discussed to the extent that it can select and use policy instruments to support systemic problems in the innovation system. The policy instruments discussed are neither evaluated nor structured. Moreover, it is not clear how they were identified. Governmental fields of action are also not considered. Finally, although systemic problems of the innovation system are linked to policy instruments, the final selection of such instruments is missing, and the explanation of the procedure for selection remains very vague.

Mazzucato 2015 – Building the Entrepreneurial State: A New Framework for Envisioning and Evaluating a Mission-oriented Public Sector.

In her contribution, Mazzucato explains for what reason and to what extent a state must intervene in the innovation system in order to support and significantly accelerate the emergence of technology-based innovations. For this purpose, the author first discusses the theory of market failure and argues that this may be sufficient for a stable state, but not if public policy is to actively shape change. As examples of such intervention, intensified public-private partnerships and the appearance of the state as a kind of venture capitalist are presented. According to Mazzucato, the state should intervene especially in high-risk technological developments that would not be supported from the private sector. It is further argued that public support has contributed significantly to the development of modern IT, biotechnology and nanotechnology. Without governmental support, the development of these technologies would proceed much more slowly. In addition, the state could create an investment portfolio with different risky investments and generate income with shares in intellectual property instead of taxes. In this way, risks are spread, and, at the same time, society as a whole benefits from successful investments [12].

DT is not explicitly addressed, yet the scientific work has mainly high-risk, capital-intensive and technology-based developments as its object. The transfer of technologies is not addressed, but the author discusses the role of the state in the context of generating innovations in detail and lists some concrete political instruments to support technological innovations, whose effects are also discussed.

Schuh et al. 2022 – Description Approach for the Transfer of Competencies and Resources in Collaborations between Corporates and Deep Tech Startups.

The aim of Schuh et al. is to identify and characterise competencies and resources that are relevant for the transfer within a cooperation between corporates and DT startups. First, the authors characterise the actors in focus, corporates and DT startups. Then, the authors discuss the reasons why collaborations exist and the relevance of competencies and resources within collaborations. Finally, a morphology is used to develop five characteristic groups, within which 26 relevant competencies and resources are identified. One of these groups is the development of technologies, which is broken down into the dimensions of technology type, technology maturity, application focus of the technology, technology resource utilization, and development focus of the technology [15].

Within defining DT startups, some characteristic features of DT are mentioned. However, these characteristics are not revisited or used in the rest of the paper. The paper deals with the transfer of technologies, but this transfer is not focused on the one between research and industry. In addition, no obstacles to this transfer are considered. Further criteria of the object and target area are not touched.

C. Literature Deficit

Overall, there is a lack of literature linking all three topics (DT, technology transfer, government within innovation system) considered. In addition to this general lack of scientific literature focusing on DT, the analysis shows that existing literature hardly instrumentalizes DT characteristics for further elaboration. Also, there is a lack of publications that show thematic overlaps with technology transfer or the role of the state in innovation systems. In scientific approaches that focus on technology transfer, DT is not considered. In contrast, barriers to technology transfer are discussed extensively, within the works of both Meißner and Corsten providing a comprehensive overview of possible barriers to technology transfer [36], [56]. Therefore, barriers to technology transfer of DT need to be comprehensively elaborated based on the linkage of existing literature.

Additionally, governmental support options for technology transfer are only sporadically presented within literature, e.g., in the contributions of Meißner or Wilhelm – with a lack of evaluation or structuring of these options [31], [56]. Occasionally, support options are linked to barriers, but this happens neither comprehensive nor systematic. Likewise, a derivation of governmental fields of action in the DT innovation systems is missing.

Finally, there is a lack of a systematic approach to linking obstacles with support options. In Fig. 2, the results of the literature analysis are summarized.

Level of detail within literature: ○ Not elaborated; ◔ Almost not elaborated; ◑ Partly elaborated; ◕ Widely elaborated; ● Fully elaborated

	Object Area			Target Area		
	Consideration of Deep Tech characteristics for further analysis	Consideration of technology transfer with a focus on transfer barriers	Consideration of the role of the state in the innovation system	Determination of transfer support options	Evaluating and structuring governmental instruments within innovation support	Derivation of state fields of action and linking transfer barriers and support options
I) Focus on Deep Tech						
Bertram 2011	◔	○	◑	◔	○	○
Schuh et al. 2022	◑	◔	○	○	○	○
Weyant 2011	○	◑	◔	◑	◔	◔
II) Focus on technology transfer						
Corsten 1982	○	●	◔	◔	○	◑
Fichtel 1997	○	◕	○	○	○	◑
Friedrich 2014	○	◑	◕	◔	◔	◔
Meißnerr 2001	○	●	◕	◑	○	○
Wilhelm 2000	○	◑	◑	◑	◑	◑
III) Focus on the state within an innovation system						
Dunkel 2005	○	◑	◕	◑	◔	◑
Mazzucato 2015	○	○	◕	○	◔	◔
Rasmussen & Rice 2012	○	●	○	◕	◕	◕
Sauer 2018	◔	○	◕	◔	◔	◑
Welsch 2005	○	◑	●	◑	●	◕
Wieczorek & Hekkert 2012	○	○	◔	○	◔	◕

Fig. 2. Result of the literature review within different areas of investigation [1], [12], [15], [29], [31], [36], [54]–[61].

IV. Methodology

From the deficits identified in the literature review in Section III, the theory-based need for action is derived, which consists of using the characteristics of DT for extracting barriers within technology transfer and additionally identifying governmental support options within this context (see Section I).

Initially, barriers and boundaries within the technology transfer of DT will be elaborated based on a structured literature analysis. A second structured literature analysis is used to identify governmental support options within the technology transfer of DT. Included in its synthesis, the barriers as well as options identified will be connected and lead to a result to support decision makers in improving the technology transfer process.

The procedure for systematic literature analysis applied is based on a mix of two methods of analysis, the *STARLITE* methodology (*Standards for Reporting Literature Searches*) [62] and the *PRISMA* method (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) [63]. The initial step of the literature analysis is the determination of the databases to be searched. The databases are selected based on their subject orientation and the possibility of filtering the results with the help of database-specific tools. To consolidate the results of the various databases, as envisaged in the *PRISMA* statement [63], the compatibility and uniformity of all subsequently required criteria, such as keywords, document types, etc., must be ensured. This is followed by the uniform definition of keywords and search strategies, including different languages. From the process point of view, however, the described definition of filters and exclusion or inclusion criteria for refining the results only takes place after the initial execution of the database search. This is required since these specifications are strongly dependent on the quality and quantity of the preliminary results and therefore cannot be defined before the search. The search ends with an indication of the final number of entries obtained in the database and indication of the date of the search. This procedure combines the advantages of both methods and allows both a systematic procedure and a comprehensible documentation of the search.

A. Approach to Derive Barriers to Technology Transfer of DT

The section presents the databases, keywords and search strategy used in the systematic literature review to identify barriers to technology transfer of DT. To control complexity, the databases used are limited to four online accessible databases. These databases are both general and subject-specific. To fulfil the requirement of topic-related and comprehensive research, the research is extended by approaches of further scientific disciplines. This enables the possibility to include sources that go beyond technology management literature. The *German National Library*, as the largest central archival library in the *Federal Republic of Germany*, maintains an index of all publications published in Germany since 1911. In addition, it ensures the availability of media from abroad in Germany. The *German National Library* comprises a database covering all fields of science and, thus, does not focus on specific subject areas, just like the second utilized database *WorldCat library*. For this reason, the scope of the search is extended by consulting the *SpringerLink* database, which is specifically geared towards publications and specialist literature from the fields of medicine, science and technology. This selection is supplemented by searching within the *Scopus* database, which contains international publications with a focus on the natural sciences, technology, medicine, social sciences and arts. Following the research procedure, keywords are defined and used to identify barriers of technology transfer. For the search, frequently used synonyms of transfer barriers "technology transfer* barrier*, technology transfer* obstacle*" are used in both German and English to include results from the international research landscape and thus to select the scope of observation as broad as possible. No restrictions are made regarding the search parameters: year of publication and document type since these would unnecessarily restrict the scope of the search.

Finally, the relevant publications are systematically analysed to outline DT-specific barriers to technology transfer. For such analysis, an individually designed procedure is more effective due to the specificity of the desired knowledge gain [64]. According to Leedy et al., the research results should be organised based on defined criteria and synthesized in a targeted manner [65]. Following this recommendation, the analysis and synthesis of the publications for the identification of transfer barriers are carried out in a four-step procedure presented in Fig. 3 and outlined below.

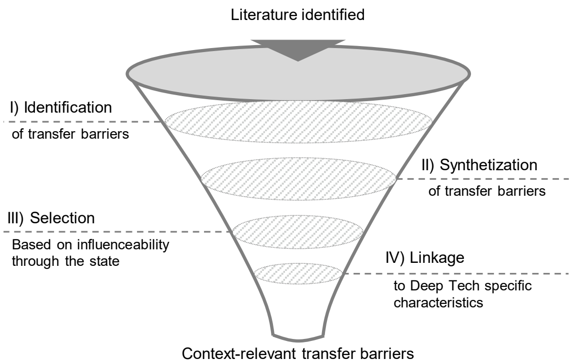

Fig. 3. Approach to prioritize DT transfer barriers.

Within the first step, the researched publications are examined holistically to identify generic transfer barriers mentioned in the publications. These are critically analysed regarding a relationship to inter-organisational transfer between research and industry. The second stage of synthetization involves the consolidation of the previously identified barriers. Synonymous barriers are grouped under uniform clusters. A balance between the loss of information and the gain in manageability must be found at each iteration. The third stage helps select thematic-fitting barriers. Therefore, the influenceability of the barriers through the state is assessed. As the fourth and final step, the transfer barriers identified in the literature review are linked to the characteristics of DT to identify barriers that are intensified by the special characteristics. This allows for a relative comparison to other technologies as well as highlighting the particularly relevant inhibiting factors. Nevertheless, all barriers, whether particularly relevant to DT or not, are considered to provide the broadest possible scope for consideration and thus the broadest possible support for the transfer of DT for deriving governmental support options. The overall results following the presented approach are provided in Section V.

B. Approach to Derive Governmental Support Options within Technology Transfer

The section presents the specific approach to derive governmental support options within technology transfer. Due to the lack of diverse support options in the literature identified in Section III, a direct search and extraction cannot exclusively be conducted. Instead, an adapted approach is required.

In contrast to the field of support options, a large amount of international literature exists that comprehensively provides policy instruments to support innovation, i.e., innovation policy instruments. These are applicable in the innovation system, i.e., in the centre of which lies the transfer system according to Meißner [56]. For this reason, it is assumed that some of these policy instruments can be considered the transfer support options. Therefore, first, a search for instruments of innovation policy is carried out and, finally, from the set of identified political instruments, those with an influence on technology transfer are highlighted.

To ensure a streamlined literature search, the state's fields of action within an innovation system are derived (see Fig. 4) by modifying the model of Kuhlmann and Arnold, which is highly established and mentioned in relevant literature (see e.g., [34], [66]–[71]) and was presented in Section II (cf. Fig. 1). The modifications undertaken are necessary to delineate individual areas of action more clearly from one another and, thus, reduce overlaps, while at the same time achieving a higher level of detail for the analysis scope. This reduces the complexity of the model while increasing its precision. Additionally, a framework to classify the ultimately identified policy instruments is generated using this approach.

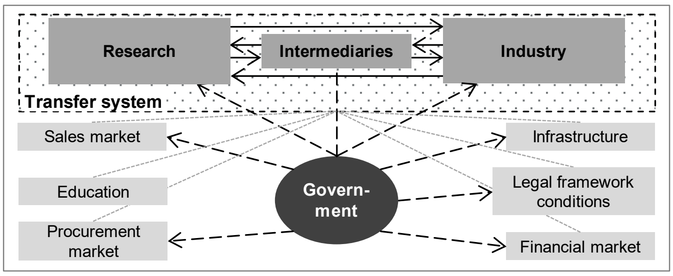

Fig. 4. Governmental area of action within the innovation system based on Kuhlmann and Arnold [45].

The single actors as well as adaptions to the original model are explicated in the following: the actor *education and research system* is divided into the separated fields: research and education, thus allowing the different roles of these two to be considered. The field of the industry stays identical to the *industrial system* defined in the innovation system according to Kuhlmann and Arnold as it is a stand-alone relevant actor for technology transfer processes. The actors of *banking* and *venture capital* listed in the innovation system as part of the *infrastructure* as well as the *financial environment* listed as part of the *framework conditions* are summarised under the field of action financial market to ensure practicability and reduce complexity of the findings. Infrastructure is required as an additional field of action. In the context of this publication, the term "infrastructure" has a brought meaning and refers to both information and communication technology as well as technical (production or R&D) equipment, the *intermediaries* as well as the relationships and connections of the actors within the innovation system (e.g., networking options). This broad understanding again helps ensuring practicability and reduces complexity. The legal framework conditions – which have high relevance within this contribution and which partially result from the *framework conditions* and the *infrastructure* – represent another field of action, including patent law, standards and norms, taxes and incentives as well as regulations and prohibitions. According to Kuhlmann and Arnold, the element of *demand* comprises both consumer demand as well as demand for intermediate products. Thus, to ensure a more structured derivation of governmental support options, the *demand* is divided into the two action fields of sales market and procurement market. Finally, the state results from the actor *political system* of the innovation system. It does not represent an action field itself, but rather takes on the central role within this framework. The state can use innovation policy instruments to positively influence the individual action fields and innovation activities.

To search for relevant literature for the identification of innovation policy instruments, it is again necessary to use the systematic procedure described at the beginning of this section – in addition to the innovation system framework presented beforehand. This approach ensures a comprehensible identification and documentation. Again, to control complexity and for reasons of usability, only databases freely available and online are taken into consideration. Likewise, both general and subject-specific databases are included. In addition to the databases used for the search for transfer barriers, Wiley Online Library and IEEE Xplore databases are screened. The Wiley Online Library is an international bibliographic database that does not focus on specific scientific topics but does have a political science section. Since the following research aims at the identification of political instruments, the search scope is specifically broadened. A description of the additional databases is found earlier in this section.

During the research process, keywords are defined and used to identify innovation policy instruments. Since the further course of the work is to identify support options for the technology transfer, the first step is to directly search for political instruments to support it. In addition, various combinations of the terms "innovation policy" and "policy instrument" are used in German and English. Due to the inconsistent use of the term "innovation policy" in German, the German-language search is supplemented by the areas of technology and research policy. An overview of the search terms used is displayed in Table I.

TABLE I

OVERVIEW OF UNDERLYING KEYWORDS

English keywords	German keywords
technology transfer policy	Politische Instrumente
	Technologietransfer
innovation policy	Innovationspolitik
innovation politics	Innovationspoli* Instrumente
innovation governance	Instrumente Innovationspolitik
innovation policy instrument	Instrumente Technologiepolitik
innovation policy tools	Instrumente Forschungspolitik

In order to define the scope of the investigation as large as possible, no restrictions are made with regard to such search parameters as the year of publication and document type.

V. RESULTS

According to the methodology and analysis approach described in Section IV, the results of the systematic literature search are presented below. After outlining the identified barriers to technology transfer of DT (section *A*), the identified governmental support options within technology transfer are presented (section *B*).

A. Barriers to Technology Transfer of DT

A search conducted on 20 June 2022 initially yielded 1889 results within the databases. Subsequently, as specified in the PRISMA phase model, duplicates were removed and search entries merged, resulting in a unique total of 1653 distinct publications. Next, the first filter criterion was established. This was necessary due to the large number of search results and to sharpen the particular relevance. For further refinement, the search results were first narrowed down with the help of a pre-selection of titles (thematic-matching). This excluded 1024 titles, reducing the number of publications to be considered to 631. The abstracts of the publications were subsequently examined. To arrive at a manageable set of publications, a high degree of overlap of the publication-content to the problem space specified in Section I was required. The remaining publications were used for the subsequent analysis and extraction of the transfer barriers. As a result of the literature search, 66 publications were identified.

Therewith, a total of 317 barriers to technology transfer were identified in the 66 publications examined at this first stage of analysis, of which 20 publications had the highest impact on the extracted results [27], [29], [36], [60], [72]–[88]. After careful consideration, these 317 transfer barriers initially identified are synthesized into 22 barriers as the second step of the approach. Therefore, synonyms of the barriers identified are derived and used to ensure such consolidation. An excerpt of synonyms and the synthesized transfer barriers is presented in Table II.

TABLE II
IDENTIFIED AND SYNONYM ADJUSTED TECHNOLOGY TRANSFER BARRIERS (EXCERPT)

Transfer barrier	Synonyms
Lack of incentive structures for transfer participation	Missing founding-incentives for scientists; Universal stakeholders do not see a transfer benefit; Insufficient financial incentives for scientific institutions; Limited recognition and reward for transfer activities; …
Lack of external transfer support	Insufficient funding mechanisms; Lack of governmental risk taking; Lack of support in exploitation of R&D results; Insufficient support in administration of projects, …
Bureaucracy within transfer process	University bureaucracy; High degree of centralization within institutions or governments; Static university structures; Innovation-averse attitude of accounting systems within science, …
Low level of technology maturity with large gap to mass production	Low transparency of R&D supply from science, Low market-fit of fundamental technological changes, lack of market for research results in Germany, Missing possibility of technology demonstration and marketing, …
…	…

As described above, the aim of the present research is to identify possible support options for the government in technology transfer of DT. For this reason, the criterion of influenceability by the state is used for the selection during the third step. This procedure reduces the number of barriers by the barrier cultural differences, bringing the final number of obstacles considered to 21.

The overall and final analysis result is presented in Table III. There, the barriers are structured into groups: DT-specific barriers (six barriers identified), structural barriers (six), inter-organizational barriers (four), as well as organisation-specific barriers (five).

TABLE III
THE IDENTIFIED BARRIERS TO TECHNOLOGY TRANSFER

Deep Tech-specific barriers	
Low level of technology maturity with large gap to mass production	Unclear application potential of the technology
High technology complexity	Long development periods
Complex regulatory hurdles	Large financial support needs
Structural barriers	
Bureaucracy within transfer process	Lack of external transfer support
Shortage of skilled personnel	Weak technology marketing
Lack of incentive structures for transfer participation	Transfer-blocking design of research landscape
Inter-organisational barriers	
Lack of relationship to suitable technology demand	Low compatibility with existing industrial infrastructures
Geographic distance	Different goals of actors involved
Organisation-specific barriers	
Lack of understanding of commercialization process	Poor large-scale technical equipment and infrastructure
Lack of knowledge about transfer success factors	Aversion to external solutions (“not invented here” syndrome)
Fear of know-how drain	

The 21 barriers to technology transfer provide a comprehensive basis for the derivation of governmental support options. Using these barriers, support options are analysed and synthesized in a targeted manner below.

B. Governmental Support Options within Technology Transfer

The aim of the following investigation is to identify support options for technology transfer. Following the approach presented in Section IV, 7507 results were initially obtained within the searched databases on 12 August 2022. Duplicates were then removed and the search entries merged, as specified in the PRISMA phase model, resulting in a total number of 6335 different publications. Based on the analysis of the publication titles as well as abstract screening, 711 publications stayed relevant of which 167 were finally included into the detailed phase of the analysis, with 35 publications having the highest impact on the following steps [53], [55], [56], [89]–[121].

Analogously to the procedure for determining the DT-specific transfer barriers (see Fig. 3), the governmental support options were derived and synthesized. In the first step, 481 innovation policy instruments were extracted from the 167 publications, which were synthesized based on similarities into 34 in the second step. In the last step, the support options were filtered regarding the identified transfer barriers and based on an assessment, whether particular barriers could be improved. The final governmental support options are presented in Table IV. Therein, the 27 government support options identified as relevant for technology transfer were structured based on the derived innovation system adapted from Kuhlmann and Arnold (cf. Fig. 4).

TABLE IV
STRUCTURED GOVERNMENTAL SUPPORT OPTIONS IDENTIFIED

Field	Support Option	Field	Support Option
Sales market	Public procurement	Financial market	Governmental loan guarantees
	Steering of private demand		Public risk capital
Procure-ment market	Export licenses		Debtor-friendly insolvency regulations
	Import permits		Interest-free/reduced loans for tech. start-ups and R&D
Edu-cation	Study programs (e.g., STEM, Entrepreneurship)		Incentives for private investing
Research	Transfer-friendly working conditions		Removal of funding restrictions
	Mobility-opportunities between research and industry	Legal framework conditions	Tax reduction for profits from patents/licenses
	Optimization of patent law at universities		Standardization and norming
	Incentivization of public research institutions		Promotion of migration
Infra-structure	Promotion and provision of technological and collaboration infrastructure		Innovation-friendly competition policy
	Promotion of intermediaries		More frequent adjustment of regulatory
Industry	Concession of the application for patents		Shortened depreciation for innovation- investments
	Direct financing of R&D projects		
	Start-up support and incentives		
	R&D tax incentives		

The 27 governmental support options provide a basis for a targeted interconnection to the transfer barriers identified. Within the approach of systematic literature analysis, especially in the phase of synthesis and analysis, some aggregations and summaries of the identified governmental support options are made to ensure practicability and manageability. This is seen as acceptable from the authors' point of view considering the systematics as well as the proven validity of the used approach.

VI. Conclusion and Outlook

Based on an extensive literature review followed by different aggregation steps, 21 barriers to technology transfer as well as 27 governmental support options for technology transfer were identified. These elements were derived while ensuring relevance, consistency and applicability to the overall situation and need for action presented in Section I. Using this set of barriers as well as support options in combination with an appropriate assessment method allows identifying DT-specific barriers and suitable support options to improve situations within innovations systems of DT.

Within the literature review, initially identified factors were summarised and synthesized. Although this reduces the holistic nature of the results to a certain extent, it is accepted in favour of the manageability and practicability of the results and is at the same time in line with generally accepted literature review approaches. However, the sums of 21 barriers and 27 support options are still large number. Hence, even further reduction or aggregation appears useful in further research to ensure fast decision making and usability.

Additional areas of investigation are proposed by the authors for future research: a literature-based connection and weighting of the elements identified seams beneficial. This will help implementing a guideline for governmental decision makers to identify support options with the highest possible impact on specific technology transfer situations. Further, the 27 governmental support options present currently or historically applied measures. Based on the weighted interconnection between barriers and options, blank spots could be identified making a targeted definition and set up of new governmental support options possible. Lastly, the findings of the present paper need to be discussed and validated with relevant actors from the innovation system based on structured interviews and case studies.

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