



Technology sovereignty as an emerging frame for innovation policy. Defining rationales, ends and means[☆]

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ABSTRACT

In recent years, global technology-based competition has not only intensified, but become increasingly linked to a more comprehensive type of competition between different political and value systems. The globalist assumptions of the post-Cold War era that reliable mutually beneficial agreements could be reached with all nations, regardless of ideology, have been shattered. A previously less visible, mostly political, risk dimension has been brought to the fore by recent geopolitical and geo-economic developments. Against this background, the notion of technology sovereignty has gained prominence in national and international debates, cutting across and adding to established rationales of innovation policy.

In this paper, we propose and justify a concise yet nuanced concept of technology sovereignty to contribute to and clarify this debate. In particular, we argue that technology sovereignty should be conceived as state-level agency within the international system, i.e. as sovereignty of governmental action, rather than (territorial) sovereignty over something. Against this background, we define technology sovereignty not as an end in itself, but as a means to achieving the central objectives of innovation policy - sustaining national competitiveness and building capacities for transformative policies. By doing so, we position ourselves between a naive globalist position which largely neglects the risks of collaboration and the promotion of near autarky which disregards the inevitable costs of creating national redundancies and reducing cooperative interdependencies. We finish by providing a set of policy suggestions to support technology sovereignty in line with our conceptual approach.

1. Introduction

Although innovation policy is a long-established field in both academic research and policy practice (Edler and Fagerberg, 2017), it remains subject to constant external pressure from the broader political domain. New trends and debates regularly result in novel claims vis-à-vis innovation policy. Given that responding to these new claims incurs not only benefits but also costs, it should be accompanied by sound conceptualisation to develop a rationale and a basis for their legitimacy

and devise new measures for innovation policy. In this paper, we turn the spotlight on technology sovereignty, which following fears of losing ground technologically has come to influence the innovation policy discourse at European level and in a number of other countries (BMBF, 2021; March and Schieferdecker, 2021; Aussilloux et al., 2020). Most often, the concept has been applied to 5G technologies under the label of digital sovereignty.¹ More recently, however, its focus has swept over to other technologies as well. In Europe, for example, there are fears of losing ground, including battery production/ development for e-

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¹ For many examples, see speeches by the EU Commissioner Thierry Breton. In July 2020 his focus was on microelectronics, (https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1362) and on 11 September 2020, he talked about “technological war” and digital sovereignty (https://ec.europa.eu/commission/commissioners/2019-2024/breton/announcements/europe-keys-sovereignty_en) as well as the concept of strategic autonomy at EU level <https://publications.jrc.ec.europa.eu/repository/handle/JRC125994>.

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mobility or artificial intelligence.

In Europe in particular, it is not the first time that fears of falling behind in the international race for technology have been at the forefront of policy debates in particular evidenced by discussions about the “American Challenge” (Servan-Schreiber, 1967) in the 1960s or Japan’s microelectronics and business process innovations in the 1980s (Contzen, 1984; Duff, 1986). However, the difference now is that a number of countries have in parts aggressively questioned institutional setting underpinning free trade and equitable competition that have been taken for granted for decades. China, as probably a prime example, is not only striving for technological leadership but also openly links this ambition to a competition between different political systems and values. Increasingly, a number of countries no longer compete within the existing international rules-based framework aimed at stabilising the existing framework of international exchange. Instead, there is a growing trend to question, challenge and game the international system with the aim of strengthening one’s role in the global innovation system and gain a position of control (Kroll and Frietsch, 2022). This is a socio-technological and economic challenge of a new quality and explains why the debate on technology sovereignty has gained so much momentum in practical policy discourses. This momentum in political discourse, however, which is not limited to Europe², is not underpinned by a theory-based concept. Against this background, and based on a first conceptual step in Edler et al. (2020), we aim to develop a concept of technology sovereignty.

In this paper, we argue that the rise of technology sovereignty results from the increasing demand that states preserve their ability to act strategically (see Mazzucato, 2018, among many others) and autonomously in an era of intensifying global technology-based competition, whereby this competition is increasingly complicated by geopolitical antagonisms as well as open disagreements about core values (Joshi, 2019; Ahn, 2020). To root this argument conceptually, we draw on the embedded agency literature (Thornton and Ocasio, 2008; Thornton et al., 2015; Ocasio and Thornton, 1999), which suggests that while the actions of (public) agents are deliberate, the degree of deliberation and the scope for action available to them is limited by institutional structures in which they are embedded (cf. Giddens, 1977). Based on these theories, we conclude that the agency of states, more specifically governments, should be considered in a systemic analysis of national innovation capacities (and their evolution) as well as current and future international interdependencies, and that policies should be designed on this basis.

On a theoretical level, our conceptualization is based on two core assumptions. First, by developing an agency-based perspective on innovation policy, we clarify the relation between technology sovereignty and other pre-existing innovation policy frames, notably competitiveness and the transformation rationale (Schot and Steinmueller, 2018). More specifically, we argue that the state’s ability to exert agency is an instrumental means of achieving ultimate goals that other frames such as the competitiveness and transformation discourses normatively define. In other words, technology sovereignty is a means, not an end.

This leads to a second assumption. Earlier discourses on strategic autonomy (Krasner, 2001; Kratochwil, 2006) or the development of “national champions” (Jowett and Rothwell, 1986) understood the pursuit of sovereignty as an end. To frame technology sovereignty as an end in itself would very likely open up a Pandora’s box of innovation and industrial policies characterised by national egoism, an overemphasis of national competitiveness and the acceleration of an already ongoing

erosion of international and supranational institutions at the expense of international division of labour and technological collaboration.

Acknowledging the risk that the simplistic advocacy of technology sovereignty could pave the way towards protectionism, we develop a more nuanced concept, which, in line with March and Schieferdecker (2021), explicitly rejects the equation of technology sovereignty with increased national autarky or technological self-sufficiency. Instead, we propose that the pursuit of technology sovereignty should be understood as the attempt to safeguard public agency in the domain of technology and innovation, i.e. the ability to act independently in the face of institutional and economic boundary conditions and, in some cases, third parties’ adversarial actions. Importantly, this ability to act independently does not result from the nations’ domestic capacity alone, but also from their embeddedness into a robust and reliable network of international relations and partnerships (Binz and Truffer, 2017) to access necessary inputs. In fact, the quality and reliability of this external network may in most cases be at least equally constitutive for the degree of global technological agency that a nation can muster than its own, domestic capacities. The smaller countries are, the more difficult and the more important is their ability for agency in global innovation systems. Consequently, any autarky-inspired attempts to cut these networks must by definition be considered unfit for purpose. Thus, we position the technology sovereignty discourse between a naive globalist approach that neglects all risks stemming from ideology and geopolitics and a short-sighted nationalist approach that neglects the cost of limiting risks and dependencies by cutting itself off from existing international capacities that could be secured through appropriate policies of interdependencies. Further, in taking a decidedly government-focused perspective we do not neglect the responsibility of individual firms to work towards securing their own supply chains and access to critical competencies. However, we focus on the responsibility of the state to ensure technology sovereignty not only for economic competitiveness - and thus to support the firms in their countries - but for broader societal goals and state functions.

This paper is structured as follows. We first present a basic definition and understanding of technology sovereignty. Then, we develop a deeper conceptual rationale to capture popular misconceptions and their risks, followed by honing the concept by mobilising the notion of embedded agency. Then we discuss the relationship of technology sovereignty with innovation policy, focusing on how technology sovereignty interacts with the two dominant rationales of competitiveness and transformation. We then suggest a number of governance and policy recommendations that are derived from and in line with the developed concept. A short final section highlights what we consider to be the main benefits of a conceptualisation of technology sovereignty that considers how best to strike a balance between securing access and benefitting from open economies. We finish the article by suggesting concrete policy options, which complement and support existing policy rationales, in particular innovation policy geared towards system competitiveness and policies aiming at system transformation.

2. Conceptualisation

2.1. Basic definition and characteristics³

In accordance with Edler et al. (2020), we understand technology sovereignty as “the ability of a state or a federation of states to provide the technologies it deems critical for its welfare, competitiveness, and ability to act, and to be able to develop these or source them from other economic areas without one-sided structural dependency”.

The concept stresses the combination of reliable access to technology or relevant components that can be secured through domestic provision

² See for example the International Forum on Critical Technologies and Technology Sovereignty co-hosted by the Korean Foundation for Advanced Studies and attended by leading policy makers of the Trade Ministry and the Ministry for Science and ICT, Seoul October 5, 2022 in Seoul, <http://techforum2022.com>.

³ The basic definition and its major building blocks are taken from Edler et al. (2020).

(own capacities) and through relationships with other economic regions (external networks). In practice, there can be manifold ways of making external relations almost as reliable as domestic capacities. The strongest option is a commitment of nations to a joint legal and institutional framework to which all must adhere; the most prominent example being the European Union. A weaker option is the long-standing congruence of political interests and values that has traditionally existed in Europe's relations with the U.S. and Japan, in which shared geopolitical interests and democratic values stabilised economic relations. The potentially weakest, but at the same time possibly most common version is structural interdependence, i.e. mutual techno-economic dependence, as has been the case for some time for some value chains between Europe and China. This last option, however, can be very volatile as reliability is by definition ephemeral and depends on a specific techno-economic status quo, which can change quickly, as well as on the stability of geopolitical conditions.

We argue that the key, and therefore justifiable, motivation for the debate on technology sovereignty is that various public actors have come to acknowledge that either government itself or the wider domestic economy have become too reliant on technologies designed, provided, and thus easily influenced or withheld by potential adversaries. Conceptually, this derives directly from established concepts of sovereignty in international law, which posits that all nation states should be able to govern their internal affairs without external interference (Hinsley, 1986; James, 1986). In this respect, the call for technology sovereignty reflects governments' concerns of losing the ability to act independently in the global technological system and/or of being relegated to unfavourable positions in global value chains. There are fears that national economic actors may lose their capacity for value creation and, in turn, governments may lose the ability to provide for their own populations with a view to generating public wealth and/or addressing relevant societal challenges at acceptable costs (e.g. Huotari et al., 2020; European Union, 2020; Bauer and Erixon, 2020).

The term technology sovereignty reflects a state's or a supranational union's ambition to retain and exercise control over global processes of technological development, aligned with and building on a broader notion of "sovereignty as autonomy", which has already been highlighted in the conceptual literature (Geenens, 2017). More precisely, technology sovereignty relates to a state's or a supranational union's ambition to shape and direct global sociotechnical systems (Fünfschilling and Binz, 2017) - with the ultimate aim of ascertaining *future* economic wellbeing and the capacity to fulfil and further develop state functions for the respective population. As documented in the extant literature, the development of global sociotechnical systems is influenced strongly by differences in national institutions and policies (Fünfschilling and Binz, 2017). Accordingly, the concept of technology sovereignty put forward in this paper is an inherently dynamic concept, constantly evolving with the changing opportunities provided by and demands for new technologies and changes or potential changes in the international geopolitical and techno-scientific environment.

Fundamentally, this concept has two main dimensions, to which the subsequent analysis relates. First, the need to be able *to provide* certain technologies, which leads to a capacity-building argument intrinsic to innovation policy as well as to the call not to give away existing capacities unnecessarily for short-term economic reasons (March and Schieferdecker, 2021). Second, the need to be able *to source* without one-sided dependence, leading to a broader discussion of trade, foreign investment, public guarantees and sometimes even defence policy. At the same time, it connects to existing debates on how national particularities in support of policy and regulation allow novel socio-technical trends to gain a foothold and gather momentum (Fünfschilling and Binz, 2017; Mjörner et al., 2022).

By combining these two dimensions, the concept of technology sovereignty proposed here remains an outward-oriented and cooperative one, which acknowledges that technological novelties spread and technological regimes develop at a global level (Binz and Truffer, 2017;

Heiberg and Truffer, 2022). It combines the safeguarding of certain abilities of a particular state or union with the simultaneous protection of the legitimate interests of other states or groups of states within the existing international division of labour and global value chains. Efforts to secure technology sovereignty can and should provide a means to safeguard and dynamically adjust a nation's ability to provide or access technology it defines as critical. Ideally, concerted efforts to build an "ability to provide" can help avoid recourse to more direct, and often less effective means such as trade policy, broad-based subsidisation, government guarantees or the direct protection of power in areas of economic interest. In practice, however, tensions will remain. Giving priority to building abilities to provide over more defensive measures may have to be softened, as some of the latter measures may well be required, in particular, with respect to safeguarding and improving a nation's "ability to source" by securing access to a range of countries rather than just one.

Regardless of the means chosen, however, measures to retain and build technology sovereignty should - in their emphasis - be proactive, not reactive, strategically planned and forward-looking, rather than retaliatory and defensive. Their ambition should not be to force other nations into dependency, but to strengthen a particular country's own agency by building capacities and encouraging activities in those arenas where the relevant future institutions of the global innovation system are negotiated and defined.

2.2. Prevalent risks of misconception

Although the overall objective of the technology sovereignty discourse thus rests on a legitimate basis, its wording and use in the political debate may implicitly convey an inward-looking, national, in Europe at best Europe-centric perspective. Hence, it is a concept at constant risk of being appropriated by those who - often out of conviction - construe other countries or economic areas as threats rather than potential collaboration partners (March and Schieferdecker, 2021).

Such an inward-looking view, however, stands in stark contrast to the established discourses on international trade and techno-scientific collaboration that emerged, took hold and proved their effectiveness in the latter part of the 20th century. For good reasons, the prevalent conceptual blueprint to achieving a nation's ambition of wealth and public welfare has long been a liberal model of collaboration and rules-based economic competition (Porter, 1990; Porges, 1995; Barton et al., 2006).

Alternative approaches to achieving economic progress through isolationist policies of import substitution have historically failed in South America and other places. Likewise, countries that are subject to sanctions that also affect their ability to source technologies by technological leaders (Iran, Russia, partially China) have struggled in vain to keep pace with global development or had to invest great resources into duplicating capacities readily available abroad.

In particular, since the fall of the Iron Curtain, the global institutional system has emphasized, if not international cooperation, at least the safeguarding of economic interests in free trade, which has been accompanied by unprecedented technological advances, growth and welfare. In line with this, standard economic theory encourages the intensification of international collaboration and global sharing of tasks (Dicken, 1994; Amin, 2002; Gereffi et al., 2005). Both conceptual and empirical studies have repeatedly argued that collaboration in various fields ranging from science and technology to production and trade, creates positive-sum situations resulting from an optimisation of resource deployment according to the comparative and competitive advantages of nations, at least if trade arrangements are free and fair (Persson, 2010; Nomaler et al., 2013; Guerrero-Bote et al., 2013; Rodrigues et al., 2016; European Commission, 2016).

In consequence, a growing number of trade agreements have been signed, tariffs reduced and intellectual property rights strengthened internationally (Barton et al., 2006), even if regular, implicit and explicit

challenges to the overall system have remained common, providing clear evidence that a power dimension is still involved (Read and Perdikis, 2005; Mckinney, 2009).

Hence, the emerging need for greater sovereignty stems less from concerns that rules-based international trade and scientific exchange can no longer provide static gains. Rather, it results from the observation that international shifts in technological capacities in combination with geopolitical disputes and an increasingly obvious clash of value systems are challenging the existing rules-based system. If that rules-based system is no longer reliably in place, however, a key premise of the abovementioned theories is no longer valid. If the establishment and adherence to any agreement becomes a politicised process, the ensuing risks may entail costs that offset potential gains. While we oppose technological independence as a statement of principle, we acknowledge that a naively globalist position that considers relations between all countries as neutral and interchangeable as in Ohmae (1990) 'borderless world', is fundamentally at odds with the last decade's developments.

The relatively stable institutional order of the 2000s and early 2010s has been increasingly challenged on two accounts. First, by new players, primarily China, openly promoting diverging economic, social and political ideologies, and seeking to either use or adapt the global institutional system to their own purpose (Mckinney, 2014; Hearson and Prichard, 2018; de Graaff et al., 2020, Hamilton and Ohlberg, 2020; Kroll and Frietsch, 2022). Second, by the fact that established players, primarily the US, starting under the Trump administration, have abandoned traditional commitments in foreign and economic politics, damaging the confidence of the global community in the former main proponent and guarantor of the rule-based order (Brewster, 2018). Under these changing framework conditions, international alliances long considered stable, and institutions to safeguard economic interests long taken for granted proved more fragile than expected, eroding established belief in multilateralism. At the same time, individual, export-dependent countries such as Germany turned a blind eye to acknowledge the inevitable consequences of recent, geopolitical shifts, some of which were entirely foreseeable (Kroll and Frietsch, 2022).

In parallel, nationalist policy-making has been on the rise, also within Europe since the mid-2010s. Against this background, there is a risk that the concept of technology sovereignty will be misused as a compliant tool by those seeking to dismantle free trade institutions, limit international collaboration and, more generally, reduce openness in international exchange. Although any equation of technology sovereignty and technological autarky is an obvious misconception (Edler et al., 2020; Grant, 1983), related discourses may nonetheless be hijacked by political actors and hence must be handled with care. All too swiftly, they become blurred in other, only marginally related discourses on (inter)national security or traditional industrial policy, which has a specific sector focus.⁴ To avoid such misappropriation and to reap the benefits associated with a multilateral notion of technology sovereignty in practice, the concept needs a strong theoretical basis, which has been lacking so far. In the following section, we therefore propose a conceptual foundation for a multilateral version of the technology sovereignty discourse that is grounded in the concept of sovereignty as agency (Giddens, 1977), while fundamentally renouncing any equation of sovereignty with self-sufficiency or autarky.

2.3. Conceptualizing technology sovereignty as embedded agency

While theoretical models of international trade tend to highlight the overall benefits of free trade, these are unevenly distributed among the

⁴ For example, Soete (2007, p. 273) defines industrial policy as "structural policies designed to strengthen the efficiency, scale and international competitiveness of domestic industrial sectors, typically contains an element of national champion, of self-reliance in bringing about economic growth and development".

trading partners. In particular, countries specializing in the value-intensive, high-tech parts of global value chains, robustly take a larger share of the returns associated with globally dispersed production and trade (Crook and Combs, 2007). This explains why countries typically seek to upgrade their technological bases in order to be able to specialise in the high-value activities in global value chains (Janger et al., 2017; Acharya, 2017; Wu, 2018). Constructing or maintaining technological bases requires mastery and control of key technologies. This is why (legally) sovereign nations subjected to global technology competition are increasingly concerned with actions to control the technologies considered relevant, either by developing them domestically or obtaining secured and stable access to them (Edler et al., 2020, BMBF, 2021, Aussilloux et al., 2020).

Against this background, we identify three weaknesses in liberal theories of global competition that interrelate and mutually reinforce each other and which require us to rethink our positioning on the present cooperative paradigm in international relations in science and technology. Overall, liberal theories of global competition display three main shortcomings of relevance for our argument. First, the focus on static optimisation, ignoring the dynamic dimensions of risk. Any international division of labour increases the vulnerability of supply chains, by which the countries' ability to act can become unduly exposed to external shocks whether of natural or political origin (Dicken et al., 2001; Dicken, 2007; Levy, 2008; Coe et al., 2008). Second, the concept of optimisation in a stable system is built on a conservative notion of innovation and production (Romer, 1990). This underestimates the ease with which technological advances can enable other emerging countries to leapfrog into new technological paradigms and challenge incumbents (Brezis et al., 1993). Third, the assumption, that emerging nations will play by the rules is open to question. These will, in contrast, seek to build and exploit dependencies and change the established terms of collaboration to their benefit. Challenges to established configurations of power and influence (and respective reactions) are therefore to be expected (Wu, 2018; Hearson and Prichard, 2018; Nicolas, 2016), including those stemming from competing value systems.

The consequence is that the premise of stable global rules-based systems, exchange patterns and technological paradigms and hierarchies is untenable. Both in the past and today, rules, exchange relationships and technological hierarchies have always been subject to dynamic change, driven by the evolving interests of leading nations and changing global norms, e.g. concerning sustainability (Barton et al., 2006; Skogstad, 2015; Krapohl et al., 2020).

While not concluding that mainstream liberal economic theory is wrong in promoting openness and exchange, we contend that some of its premises are too simplistic. A more differentiated approach is required during periods of dynamic technological change and challenges to the global institutional system, particularly if they co-occur with the prevalence of competing value and economic systems.

To construct such a differentiated approach, we conceptualise technology sovereignty from an embedded agency perspective (Thornton and Ocasio, 2008) of globalised technological competition. Embedded agency has evolved from the more general debate on whether the surrounding socio-institutional structures are determinant in shaping an individual's behaviour or whether the individuals are endowed with agency, i.e. the ability to act freely and in a self-motivated manner (Giddens, 1977). Since the 1980s, this discussion has increasingly evolved into a synthetic discourse, which posits that, while structures shape agency, agency as such does exist and enables actors to influence future structures (Giddens, 1984).

Embedded agency is thus a concept describing the interplay of individual action and institutional structures, where structures are 1) both enablers and limiters of action and 2) emergent from past collective action (Battilana and D'Aunno, 2009). This sociological view of agency has clear links to technology policy and sovereignty. For example, a state seeking to specialise its economy in a relevant technology needs a certain level of technology sovereignty on the one hand, which enables a

certain level of control or command of that technology. On the other hand, its sovereignty will constantly be challenged within a framework of technology competition by competing nations and by strong individual firms that increasingly dominate important areas of economic activity and societal development by applying global internet-based platform business models. These challenges limit its level of technology sovereignty. As a consequence, while a country may remain legally sovereign, this sovereignty is limited, because it is embedded within structures of globalised economic and technological interdependencies. This becomes a threat to the country if those interdependencies turn into one-sided structural dependencies.

Beyond clarifying the boundaries of agency in international structures, embedded agency also highlights the global structure and the interplay of state action. Any action taken to preserve technology sovereignty will affect the (international) structure and thus shape the global system. For example, if a country withdraws from international investments and re-shores technology production, this will cause others to react and will create new value chains and trade patterns, which in turn will influence agency in the future. On the other hand, if a country invests in the development of international standards, it can enhance its own influence on market structures and consequently its own agency.

Conceptualizing technology sovereignty from the perspective of embedded agency raises two questions: First, how can a state devise STI policies to best serve the needs and demands of its population under the current structures? Second, how can a state devise STI policies to ensure the largest possible influence on future structures? These questions are obviously open-ended and do not prescribe any particular course of action. Instead, they welcome the integration of insights on effective innovation policies from different theoretical backgrounds and logics, including market failure theories, socio-technical transformations, international relations and trade politics, to name but a few. In particular, the agency perspective does not preclude that international cooperation in science, the creation of strategic multinational technology alliances or the free flow of knowledge within certain economic areas are the best way to achieve the STI-related goals or technology sovereignty in a specific setting.

Although the embedded agency perspective does not itself predispose concrete innovation policies, it provides a very clear interface to the various literatures on systems of innovation, from which clear propositions can be derived about which policies seem advisable and which do not. This interface becomes clear with respect to the methodological apparatus of embedded agency theory, which consists of two building blocks. The first is “actors”, which, in conjunction with the notion of technology sovereignty, emphasises the role of governments and supranational organisations alongside that of large companies and research organisations. The second is that of the organisational field, which can be understood as a (constantly changing) playing ground that determines the rules of the game. As we highlighted above, in the context of technology sovereignty, the generic game that is played by the actors is technological competition in relation to a specific technology or a set of mutually dependent technologies.

In this context, it is worth noting the parallels between an organisational field on the one hand and an innovation system on the other. The innovation systems literature (Nelson, 1993; Edquist, 1997, 2010, among many others) often uses constructs very close to the organisational field literature, albeit with a different wording and a less pronounced emphasis on the role of state action. Of particular usefulness for our definition of technology sovereignty is the concept of a (global) technological system of innovation. The technology systems literature (Carlsson and Stankiewicz, 1991) has a very compatible focus, in particular as some more recent variants take a broader perspective on technological systems delineated by functional challenges (Bergek et al., 2015; Markard, 2020).

However, the concept of the technological innovation system is more limited than that of an organisational field in the sense that it predicates a techno-centric view, which may be a reasonable framework for STI

discourses focusing on technological innovation. STI discourses that refer to transformative change and thus include not only technological changes but also changes in social habits and practices, policies, and even societal values (Geels and Schot, 2010; Coenen et al., 2012) are not easily captured within an innovation system framework alone. More specifically, we argue that, so far, the role of governments as agents has been underrated in the innovation systems approach, which becomes particularly problematic when, as is the case with technology sovereignty, international relations and government level exchanges play a major role. In a situation of dynamic changes in the global system, the traditional view of institutions as providing a largely stable, national-level framework cannot suffice. Instead, institutions should be seen as the result of a continuous sequence of deliberate and in part, strategic government actions, thus placing government centre stage as a key actor, on both the national and the international scene of establishing and renegotiating rules-based systems. In sum, thinking along organisational fields rather than technological ones is helpful, as it broadens the view to include elements that are critical for the consideration of technology sovereignty, but not normally included in the technology systems approach.

In the next sections, we explain what the loss or lack of technology sovereignty means for innovation policy in general and what policy makers need to do to address it. We then explain how the agency perspective of technology sovereignty specifically contributes to the currently predominant discourses on innovation systems, inspired by the logics of economic competitiveness on the one hand and transformative discourses on the other hand.

3. Implications for innovation policy and its prevailing rationales

3.1. Technology sovereignty and innovation policy

As stated above, technology sovereignty has already become an issue of major concern for innovation policy makers, but it requires clearer conceptual framing and grounding. As we argued above, it should be conceived of as a means to achieve existing innovation policy objectives more effectively, rather than as an end in itself. To further illuminate the issue, it is useful to describe in more conceptual detail why the loss or absence of technology sovereignty can be detrimental to policy makers in their pursuit of innovation policy objectives. However, we begin by examining under which framework conditions governmental action can be justified at all.

Conceptually, technology sovereignty emphasises building up capacities and safeguarding technological access (March and Schieferdecker, 2021; Edler et al., 2020). These become particularly pressing when a state's own capacities and relationships with other countries become insufficient to ensure access to technologies deemed critical to successfully perform the public tasks for which government has been granted a mandate. Therefore, innovation policy guided by technology sovereignty considerations aims to focus on selected, strategically identified domains. Likewise, potentially disruptive policies outside the traditional domain of innovation policy (industrial, trade, investment or security policy) should be deployed carefully and with moderation. In fact, new measures seem to be justified only when there is an obvious structural failure of past innovation policies, when the global technological system or domestic societal preferences have substantially changed, or when there is a need to respond to a lack of systemic resilience and redundancy in the face of crises such as COVID-19.

Given the benefits of open, interdependent systems in enabling static efficiency gains, state intervention is thus only justified where states or groups of states experience or expect a loss of agency with regard to fulfilling core governmental tasks, as a result of the lack of access to critical technologies. To improve the positioning of a nation or supranational union in global technological competition is thus not per se a suitable measure and certainly not a panacea.

Against this background, public policy that takes technology sovereignty into account will have the greatest justification and develop the highest leverage the earlier a concrete challenge is identified with respect to a particular domain of government agency, i.e. if there is still time to focus public activities on constructive, capacity-building measures that are intrinsic to the innovation process (rather than having to forfeit known benefits by limiting free trade or global investment). In order to ensure the success of innovation policies focusing on creating or restoring agency, two main issues need to be addressed.

First, it is essential to clearly specify the technologies, or more precisely the element of the innovation and the value chain in which greater sovereignty is required. Since numerous studies document the extent to which the generation of technological innovations is characterised by an international division of labour, the idea of relocating entire innovation chains to a single country, or to a well-integrated multinational economic area (such as the EU), is very questionable at best. Thus, it is critical that there are clear criteria to define those technologies for which a state or a group of states takes action to increase sovereignty.

Second, in order to identify such technologies, it is essential to determine precisely in which functional context the respective technology is considered critical, as this will define why, how, in what timeframe and with what degree of urgency it will have to be addressed. Here, we can distinguish three major functions at the systems level for which a state or a group of states need to have sufficient agency in terms of critical technologies: First, technologies that fulfil central state functions (defence, security); second, technologies that support long-term economic competitiveness; and third, technologies that support the pursuit of societal preferences in the context of targeted socio-technical transformation.

The following sections outline the relevance of technology sovereignty for the second and third dimensions in particular, as questions of technology sovereignty have always been at the forefront of ensuring the agency for exclusive state functions such as defence. The reason for not considering defence issues is that this touches upon the provision of non-excludable and non-rivalrous public goods which are not supplied by the market and have therefore, always been the domain of the state.

3.2. *Justifying technology sovereignty based on an economic welfare objective*

As outlined in the introduction, a nation's ability to enable its firms to compete freely and successfully in the global technological system is essential to ensure sufficiently high-levels of welfare and to provide for its population in the long run. As discussed above, there is a long tradition of economic thinking that state intervention to support the competitiveness and innovativeness of its systems is essential in the context of market and system failures. The subsequent paragraphs outline how this need to ascertain the competitiveness of firms and the long-term agency of states to achieve and maintain technology sovereignty adds another rationale for state intervention.

While international competition itself is driven by companies and not by states, their ability to compete relies on a number of central factors from which a rationale for state intervention in the pursuit of securing international competitiveness can be derived. More precisely, the ability of companies to compete freely depends on at least five main basic principles that are at least partially within the domain of government (Edquist, 1997; Kuhlmann and Arnold, 2001). First, the availability of talent, which, in turn depends on the availability of excellent basic and higher education in key fields. This may be privately organised, but in most countries, it is de facto at least partly under state control. Second, it depends on knowledge, including those technologies developed in and transferred from the research sector as this is deemed a public domain because of the associated knowledge externalities. Third, it depends on functioning value chains, where the state's task is to keep these open and reliable by setting appropriate institutional frameworks (e.g. trade agreements). Fourth, it is reliant on suitable, modern infrastructure, in

particular in the digital domain, which should be financed at least to some extent from public funds, as companies will underinvest due to free-rider incentives. Fifth, and finally, it depends on and is shaped by regulation and standardisation, which fall either directly under the remit of the state (regulation) or can be monitored, encouraged and incentivised by government agencies (standardisation).

Further, short-termed economic rationales of the owners and shareholders of companies may lead to selling off critical competences to foreign competitors, even if this is not in the interest of the wider economy and may limit technology sovereignty.

Nevertheless, the core activities in international competition are performed by the companies themselves and not the state. Technology development, sales, trade, business and importantly the financing of these activities remain largely outside the remit of public authorities. Despite the above-mentioned exceptions, this fundamental paradigm is not questioned by legitimising state action in pursuit of national competitiveness.

In contrast, public efforts to retain or regain technology sovereignty can be motivated by the need to enable, safeguard and, if need be, defend the robust foundations as well as a favourable and equitable framework of global competition. Fundamentally, this can be derived from three central rationales for state functions, which do not deviate substantially from mainstream economic theory. First, from the ambition to ascertain the foundations on which future competitiveness rests, in particular in the area of basic and strategic, mission-oriented research, where public good characteristics are most obvious (e.g. Stiglitz, 1999; Williams, 2016; Griffioen et al., 2021). Second, from the ambition to ascertain the physical and institutional infrastructure on which international competition depends (Gruber, 2019; OECD, 2020; Greenstein, 2020). Third, from the ambition to safeguard and, if need be, defend a level playing field for global competition by acknowledging and, where unavoidable, defensively and deliberately countering other nations' prevalent use of non-market means like large-scale subsidisation or protectionist trade policies (Nicolas, 2016; Weinhardt and Brink, 2019; de Graaff et al., 2020).

Technology sovereignty as an instrumental rationale calls for securing access to the knowledge relevant for competitiveness as a public good, even if the trade-off is allowing other countries to access this knowledge base. Furthermore, access to increasingly global physical infrastructures has to be assured for the companies of the respective country, again potentially in exchange for allowing foreign countries to access their own infrastructures. This argument also holds for access to institutions, e.g. patent courts in Europe for Chinese companies. Finally, violation of the rules of global competition by single countries might not only challenge the short-term competitiveness of domestic companies, but also the longer-term technology sovereignty of the country at large. This would require government to undertake counter strategies that are more comprehensive and focused on the longer term than the short-termed policies of securing its country's own competitiveness.

Overall, state action to achieve technology sovereignty can therefore be legitimised from a competitiveness perspective, albeit in a limited manner. At least in welfare states, governments have the clear mandate to ensure future prosperity for their electorate. Without technology sovereignty, however, such prosperity cannot be achieved and sustained. Accordingly, governments are mandated to safeguard and improve their nation's international standing and agency. Without a suitable foundation and reliable framework, which only the government can provide, economic actors will not be able to ensure national welfare in the long run.

It is precisely this strategic, capacity-oriented perspective at the core of this rationale, which is important. While protectionism and short-termed interventions into the economic process may help specific firms transiently, they do not automatically build lasting national capacities. Accordingly, they cannot be readily justified based on the above argument, unless they are a direct response to other countries' already existing or evidently planned interventions of a similar nature.

3.3. Justifying technology sovereignty based on a systems transformation objective

As stated above, a rather recent but increasingly important rationale for innovation policy is the contribution it can make to the transformations needed to tackle major societal challenges. This became most obvious in the COVID-19 crisis, where the quick mobilisation of innovations through collective efforts became an imperative. However, transformative policies are now defined in all kinds of societal areas, most notably relating to climate change and sustainability. While the generation of innovations, more precisely technological innovations, will not be sufficient for the transformations needed, many societally desirable transformations will not happen without the generation and diffusion of technological innovations. The argument for this rationale is a long-standing one, and different policy intervention rationales have been developed as a result. Most notably, the rather technocratic mission-oriented innovation policy approach suggested by Mazzucato and the European Commission postulates that the state can define concrete goals that can be achieved by targeted innovation policy interventions, supported by complementary policies as needed (Mazzucato, 2014, 2018; Kuittinen et al., 2018; European Commission, 2021). A second variant, transformative innovation policy, postulates that the state can support transformations that are emergent and typically follow a bottom-up rationale. In this case, state interventions strengthen inherent dynamics to replace incumbent socio-technical regimes with those that are more akin to desired societal outcomes (Schot and Steinmueller, 2018, Molas Gallart et al., 2020). These rather idealistic extreme variants of innovation policy supporting transformation have since been complemented by a whole range of different approaches and types (OECD, 2021; Wanzenböck et al., 2020; Janssen et al., 2020).

Despite their differences, all these conceptual approaches and their empirical applications have three things in common: First, the legitimacy of the state rests on its ability to mobilise innovation for transformation in order to achieve the desired change, rather than on input additionality or improving how the innovation system works (Edler and Fagerberg, 2017; Boon and Edler, 2018). Second, the state needs to ensure that investments in technological innovation are directed towards achieving societally desirable goals. Third, many of the societal challenges tackled are shared by other countries and are in themselves transnational in nature and thus benefit from international learning and cooperation.

System transformation as a leading rationale is a challenge in every respect and even more imperative to secure technology sovereignty. If the pursuit of major political goals depends on the availability and roll out of very specific technologies, failing to develop these technologies nationally (or at EU level), to secure access to them or to provide substitute technologies directly undermines the legitimacy of the state. Further, any development triggered by technology sovereignty considerations that would in response undermine international cooperation and learning will also reduce the ability of a country or groups of countries to tackle the shared challenge of system transformation. The loss of economic welfare as described above would be accompanied by a loss of societal welfare that is linked much more directly to the failure of the state to deliver.

At the same time, this top-down approach of technology sovereignty orchestrated by public policy can be complemented by bottom-up dynamics in transformation processes. Transformative innovation policy is characterised by a much more conscious and stronger societal discourse about the desired direction of change and the means to achieve it. This bottom-up element of transformative innovation policy can help to define technology needs more explicitly than in traditional policy approaches. Anticipatory discourses (Schot and Steinmueller, 2018) also support the search for alternative solutions and experimentation, and this collective exercise can be one way to manage situations of poor access to important technologies.

4. Potential policy actions

In the previous section, we outlined how technology sovereignty cuts across the established competition/welfare rationale on the one hand and the transformational rationale on the other as a precondition for these two primary rationales to be successfully achieved. This raises the question of whether any specific policy recommendation can be justified based on the notion of technology sovereignty, which goes beyond the mandate of the other two rationales. Understanding technology sovereignty as safeguarding agency can motivate measures in the field of industrial, competition, trade or investment policies in cases where the positive build-up of technology sovereignty will not be sufficient, which would otherwise be considered out of scope. From a technology sovereignty perspective, however, these may be used - with moderation - to avoid structural dependencies.

In the following, we explain why (rationales) and how (policies) the acknowledgement of technology sovereignty as an important precondition justifies and suggests a number of interventions that go beyond those usually mandated by the established rationales of innovation policy. To highlight how those rationales (why) and policies (how) relate to the three target dimensions of STI policy competitiveness (end), transformation (end) and technology sovereignty (means), we summarise the main arguments in two tables. Table 1 below depicts the rationales, Table 2 at the end of Section 4 shows the policy instrumentation. We depict technology sovereignty in these tables alongside the two goals it contributes to in order to highlight the relationship.

4.1. Developing strategic intelligence for technology sovereignty

Innovation policy that considers technology sovereignty as a means requires the state to make careful assessments of which technologies are actually critical and which threats to their provision or access to them actually exist (Edler et al., 2020).

Strategic intelligence is certainly needed and widely applied for policies to support transformation and competitiveness. However, strategic intelligence considerations for technology sovereignty in particular require an overarching assessment of a country's position regarding technological competitiveness and power relations in international value chains. This is a specific requirement emanating from the concept of technology sovereignty as a supporting dimension of competition and transformation policies. The assessment of technology sovereignty is no easy task and puts higher demands on a state's strategic intelligence capabilities - arguably much higher than those resulting from other previously adopted innovation policy rationale.

The analytical or strategic intelligence capabilities of a country or a multinational economic area (such as the EU) are not only relevant for a functioning innovation system (e.g. Hekkert et al., 2007), but also form the basis for deciding which technologies are critical and how to secure access to them. Methodological and analytical competencies must be available in order to be able to investigate the main dimensions with regard to technology sovereignty in a technology-specific manner and with the necessary level of granularity.

Several main aspects have to be diligently considered in detail before any political efforts towards increasing technology sovereignty can be initiated. First, whether and why a technology is currently critical or will become critical in the future, including the functional context in which it is critical (economic competitiveness, meeting key societal needs, contributing to sovereign tasks), i.e. what motivates state intervention. Second, how and to what extent access to this technology is or could soon be threatened; including a differentiated risk assessment of current sourcing patterns and strategies. Third, within which spatial-political system boundaries should technology sovereignty be achieved and a definition of what is needed to achieve it in this specific area. Fourth, which competencies and resources the country or spatial-political system in question already (or still) possesses, which ones it is confident of developing in the short to medium term, and which will have to be sourced

Table 1
Rationales in relation to three target dimensions of STI policies.

Type of policy/discourse	Competitiveness	Transformation	Technology sovereignty
Overarching legitimization	Maintaining competitiveness and assuring efficient market allocation	Systemic inertia to sustainable change	<u>Preserving agency as to technologies relevant to support competitiveness and transformation</u>
Pro-active and mobilising policies (capacity enhancing)	Assuring competitiveness in technologies related to upcoming social and economic challenges	Understanding the impact of current and future technologies on sustainability	Assuring the state functions reliant on critical technologies
Developing strategic technological intelligence	Avoiding private underinvestment in knowledge and insufficient systemic cooperation	Avoiding lock-in in sustainability relevant technologies and offering technological solutions for transitions	Improving technological capabilities related to critical technologies
Support of STI (competencies, research and infrastructure)	Exploiting the state's advantages in internalizing risks associated with radical innovation	Supporting technologies/firms in deploying technological solutions for transitions	Supporting firms relevant for critical technologies
Innovation-oriented public procurement	Avoiding cost duplication, counteracting indivisibilities, reduce the stickiness of knowledge	Creating critical mass and exploiting spill-over based positive externalities	Building trust, creating mutual interdependencies and securing access to relevant technologies
Supporting international collaboration and institutions	Supporting the competitive position of innovative domestic firms	Supporting transition friendly imports	Avoiding one-sided dependencies or loss of domestic capabilities
Reactive and defensive policies (capacity protecting)	Supporting the competitive position of innovative domestic firms	Supporting transition friendly investments	Avoiding one-sided dependencies or loss of domestic capabilities
Trade policy			
Investment and competition policy			

Source: Own compilation.

from third parties for the foreseeable future, be it for commercial, environmental or other reasons (cf. Edler et al., 2020).

The strategic intelligence requirements are not only analytical, i.e. mobilising bibliometric, technometrics techniques and economic analyses. They are also discursive, i.e. it is critical to establish foresight processes⁵ that outline possible future trajectories of societal demands and technological developments that can be used to underpin any decisions about criticality and technology sovereignty.

4.2. Policies to secure or gain technology sovereignty

We suggest that established innovation policies are and remain critical for the support of competitiveness and transformation in their own right. The claim that there are additional policy considerations because of the need for technology sovereignty does not detract from the basic importance of innovation policy in its own right. In contrast, as technology sovereignty is a further means to support competitiveness and transformation, it is a necessary complement of innovation policy.

Further, if we accept the challenge of technology sovereignty, certain claims towards the state are novel in different ways. Transformation-oriented policies as well as innovation policy to ensure competitiveness have not systematically mobilised planning capacities to anticipate technological needs and analytical tools to ensure that they can be met in the geopolitical land geo-economic context. In the context of technology sovereignty as a necessary condition for self-governed transformation and competitiveness policies, it is inevitable that the state takes technological decisions and mobilises strategic intelligence and sovereignty conditions. This includes a better coordination with trade and foreign policy that goes beyond what we see in established transformation and innovation policies.

4.2.1. Mobilising established innovation policies for technology sovereignty

The following policy actions can be considered to secure or regain technology sovereignty in a specific domain. The compatibility of the technology sovereignty approach with the established competitiveness and transformation rationales suggests that the policies they call for will also be relevant from the technology sovereignty perspective. Since technological capabilities form the foundation of technology sovereignty, they are included again here, even if their justification does not require the adoption of a technology sovereignty perspective. We do so in order to convey that the overall balance or focus of policy intervention in these fields would only be influenced very moderately should a technology sovereignty perspective be adopted in the manner proposed in this paper. Regardless of whether complementary measures are required, we highlight the following five areas as the core fields of intervention in innovation policy. We also emphasise that those policies are not necessarily at a national level. In economic areas with sufficient political and economic integration to develop policies at transnational or even supranational level, most notably the European Union, those policies may better be developed and implemented on that level or coordinated between the supra-national and national level.

Competences and research: To maintain their ability to produce relevant technologies and products in a dynamic environment, countries have to generate technology-specific knowledge using the classic instruments of research and innovation policy, as recently advocated by the German Federal Ministry of Education and Research, for example, under the heading of “ability, not autarky” (March and Schieferdecker, 2021). Beyond the investment in R&D, this requires a critical mass of knowledge carriers, which can only be formed by teaching the corresponding content at universities. The ongoing discussion on the gap in professorships in battery technology or Open Source (Blind et al., 2021)

⁵ See, for example, the scenarios based on the consultation of various stakeholders related to the future of the 5G supply chain in the EU in Dinges et al. (2021).

Table 2
Policies to support three critical target dimensions in STI policy.

Type of policy/discourse	Competitiveness	Transformation	Technology sovereignty
Overarching legitimization	Maintaining competitiveness and assuring efficient market allocation	Systemic inertia to sustainable change	<i>Preserving agency as to technologies relevant <u>to support competitiveness and transformation</u></i>
Pro-active and mobilising policies (capacity enhancing,)			
Developing strategic technological intelligence	<ul style="list-style-type: none"> Identifying technologies with high economic potential 	<ul style="list-style-type: none"> Identifying technologies relevant for implementing sustainable transitions Mission-oriented, SDG oriented policies 	<ul style="list-style-type: none"> Identifying technologies undergirding agency in important state functions including maintaining competitiveness and supporting politically defined transitions.
Support of STI (competencies, research and infrastructure)	<ul style="list-style-type: none"> Generic or subject-specific support for public or private R&D Publicly subsidized (higher) education Innovation-friendly regulation (in particular related to competition) Support co-operation to support innovation generation 	<ul style="list-style-type: none"> Support for R&D related to technologies/science Regulation promoting sustainability relevant technologies 	<ul style="list-style-type: none"> Support for R&D related to critical technologies Strengthen established companies or incumbents, clusters Support the foundation of start-ups Regulation promoting innovation in critical technologies
Innovation-oriented public procurement	<ul style="list-style-type: none"> Procurement with respect to highly innovative goods/services, creating lead markets 	<ul style="list-style-type: none"> Procurement of goods incorporating technologies supporting desired transitions 	<ul style="list-style-type: none"> Procurement of goods incorporating critical technologies
Supporting international collaboration and international institutions	<ul style="list-style-type: none"> Exchange programmes and research mobility International R&D alliances Safeguarding IPR via common regulation (e.g. TRIPS) 	<ul style="list-style-type: none"> International R&D alliances in sustainable technologies 	<ul style="list-style-type: none"> International R&D alliances in critical fields Influence international standardisation towards open standards (in combination with strengthening the own IPR portfolio) International coordination of regulatory framework conditions
Reactive and defensive policies (capacity protecting)			
Trade policy	<ul style="list-style-type: none"> Supporting access to export markets for innovative technologies Protecting novel, vulnerable technologies 	Orientation of trade policies towards sustainability	<ul style="list-style-type: none"> Promote bi- or multilateral trade agreements to secure access to technologies Expand international treaties on the promotion and protection of foreign direct investment (incl. TRIPS)
Investment and competition policy	<ul style="list-style-type: none"> FDI restrictions for foreign competitors M&A rules also for FDI 	<ul style="list-style-type: none"> Supporting investment in sustainable technologies domestically and abroad 	<ul style="list-style-type: none"> Foreign investment guarantees for domestic firms Investment protection policies Enforce competition policy to avoid the abuse of dominance by foreign competitors Support for diversification of sourcing

Source: Own compilation.

in Europe is one example of this.

International cooperation: Since the potential portfolio of technologies is much too large for the majority of national economies to provide the necessary research and production capacities in all the fields relevant for their technology sovereignty themselves, it is necessary to establish long-term collaborations, in particular in those areas where technology sovereignty is missing. These technologies or products often require access to specific raw materials. Therefore, an international division of labour is necessary which can be initiated for example through long-term research cooperation. In addition, international scientific and technological cooperation is essential to build up structural interdependencies and mutual trust internationally, thereby reducing the risk of unilateral dependencies in the long run.

Start-ups and entrepreneurial activity: Since the competencies and capacities of the private sector support future technology sovereignty, it is important to not only strengthen the already well-established companies or incumbents that tend to exploit their competitiveness on the basis of already existing technologies and products, but also to support start-ups in emerging technologies that are likely to support technology sovereignty in the future. In addition, a further way to support and protect the technological competencies of a nation or economic region - and thereby its agency - could be the build-up of publicly owned large technological companies in areas of strategic interest and strong global competition (Archibugi and Mariella, 2021).

Public procurement and demand-side innovation policies: Targeted public procurement can help to create early new markets or lead markets (Beise, 2004) for innovations that may become relevant for many other countries, and thus establish global technological leadership and eventually a good negotiating position to safeguard technology sovereignty in certain technological domains. In addition, for any country or federation of countries (most notably the European Union) it makes sense in the long term to design the regulatory framework in a way that provides their industries favourable conditions and incentives to perform the corresponding research and therefore also to establish production capacities in fields where there is a risk of technology dependencies.

Infrastructure: In a dynamically changing environment, all enterprises depend on an up-to-date infrastructure, in particular in the digital domain, which they can rely on in their research, development and production activities. Typically, at least the fundamentals of such infrastructures have to be provided by the public sector.

4.2.2. Additional innovation policies for technology sovereignty

In addition to these fundamental, traditional policy approaches, which should continue to form the foundation of all future research and innovation policy (March and Schieferdecker, 2021), technology sovereignty may also justify further policy action which does not necessarily follow directly from transformational or welfare rationales as such. This may only become relevant if recourse is made to the need to safeguard government agency in innovation policy. This section discusses the role of regulatory frameworks, competition/ trade/ investment policies and setting up or strengthening international institutions including international standards.

Regulatory frameworks: While the regulations addressing negative externalities, e.g. to protect the environment, have limited implications for technology sovereignty, the regulation of public enterprises and infrastructures do. For example, the EU toolbox to mitigate cybersecurity risks gives the EU Member States guidelines on how to regulate national procurement practices of 5G mobile telecommunication technologies.⁶ Here, the objective is to ensure the integrity of national physical infrastructure, an important element for the functioning of the state and therefore also for technology sovereignty.

⁶ <https://digital-strategy.ec.europa.eu/en/library/cybersecurity-5g-networks-eu-toolbox-risk-mitigating-measures>.

Competition/trade/investment policies: Competition policy addresses the abuse of dominance and monopolisation, cartels and anti-competitive agreements, mergers, liberalisation and competition interventions in regulated sectors and general pro-competitive policy reforms (OECD, 2015). As all these policy areas - one way or the other - serve the long-term survival of a sufficient number of companies in a competitive environment, they all link to technology sovereignty, albeit to different degrees.

Developing industrial capacity in selected areas: State support to go beyond the support of innovation capacities and develop industrial capacity in areas that are seen as critical is a further, increasingly important policy approach to secure technology sovereignty. This can take the form of targeted, pooled public support, as in the European IPCEI initiatives⁷ (Van den Abeele, 2021) or (partly) state-owned companies, such as Airbus in the past (Archibugi and Mariella, 2021). Measures such as the "national champion" policies should be contemplated primarily at a supranational level, such as those coordinated by the European Commission, as these may otherwise jeopardise competition on the national market and can trigger counter measures that threaten transnational dependencies.

However, competition policy might be insufficient to secure a state's technology sovereignty and has to be embedded in the broader context of trade and investment policies. Among the various dimensions of trade policy listed by the OECD (2015), international trade agreements are the most effective approach to secure technology sovereignty. In this context, governments' can also consider technology sovereignty in their activities related to market-expanding international trade agreements and through the implementation of their WTO commitments. This can be done, for example, through clauses guaranteeing access to specific technologies or goods. Further, investment policy is complementary to trade policy. Intellectual property rights and the non-discriminatory treatment of national and international investors and effective enforcement mechanisms are particularly relevant for securing technology sovereignty and international co-operation. Therefore, in 1995, the WTO launched the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). Careful considerations have to be given to whether the treatment of domestic and foreign firms following the principle of non-discrimination should be reconsidered in the context of technology sovereignty⁸. Finally, the collaboration of national investment policy authorities with their counterparts in other economies to expand international treaties on the promotion and protection of investment could also take into account the dimension of technology sovereignty, e.g. by focusing on reciprocal investments in areas relevant to the respective countries' technology sovereignty or by preventing the selling off of critical technological capacity to foreign companies or states. The monitoring of acquisitions of European companies by non-European multinationals in accordance with EU -Regulation 2019/452 is a specific example of a measure addressing both competition and trade policy.

Strengthening international institutions: Free world trade with its strong incentives for competition remains an important boundary condition to ensure technology sovereignty. Compliance with agreed multilateral regulations should be ensured by strengthening key international organisations such as the WTO. Complementary to the WTO as a governance structure for global trade, bilateral or multilateral trade and investment agreements are appropriate ways to reciprocally secure countries' technology sovereignty. New institutional developments could be also considered to complement international technical

⁷ IPCEI: Important Project of Common European Interest is a form of public subsidy to develop pooled technological and production capabilities and infrastructure in areas defined as critical by the European Union [https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014XC0620\(01\)](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014XC0620(01)).

⁸ See the debate about waiving patent rights on COVID-19 vaccines.

standards. One recent example is the ORAN Alliance, created by several globally active mobile network operators in 2018 as an attempt to increase their independence from the dominant providers of 5G technology (see Dinges et al., 2021 for its analysis and possible future scenarios).

Standardisation: Standardisation, in particular international standards as international institutions, play a critical role in securing technology sovereignty. The development of open standards in accordance with the six principles of the WTO⁹, of which openness, transparency and impartiality are the most important for technology sovereignty, (potentially in conjunction with patent pools), and their support by many international companies and research organisations can ensure access to technologies that are relevant to the vast majority of countries. The openness of standards can be promoted even more by integrating elements of Open Source software (Blind et al., 2019) and even hardware (Blind et al., 2021). These open standards prevent proprietary monopolisation of technologies, which challenges countries' technology sovereignty, if these are owned by only a few foreign companies. Consequently, open standards reduce dependencies on single suppliers within complex value chains and therefore also lower the risk of supplier failure. If national stakeholders, in particular companies but also research organisations, were to actively contribute to these, this would increase the integration of nationally developed technologies into international standards (as revealed for the United States and China by Blind and Von Laer, 2022), reduce the implementation cost for domestic companies and thereby foster not only their international competitiveness but also technology sovereignty.

In line with our discussion of agency and structuration, this section has demonstrated that many of the state actions designed to strengthen technology sovereignty will inevitably link back to the global structure. This is especially true for more defensive measures in terms of trade and investment policies, which could trigger adverse reactions from other countries and blocs, but it also holds for standardisation policies, where the positive effects could be a global market in line with the standards developed in a particular country. Understanding these feedback loops, both intended and unintended, is an important prerequisite for any balanced technology sovereignty policy.

5. Conclusion and outlook

Sovereignty discourses have proven powerful and ubiquitous, despite the fact that many authors have predicted their demise due to the increasing relevance of international integration and global institutions (Werner and de Wilde, 2001). In particular during times of crises and disruptions, i.e. when a nation's ability to maintain status-quo processes is at stake, a renewed ambition to control existing dependencies may come to the fore (Krasner, 1999; Werner and de Wilde, 2001). Therefore, it should not come as a surprise that technology sovereignty as a specific variant of sovereignty discourses has once again become fashionable after a turbulent decade influenced by the financial and economic crisis, increasing protectionism in the USA and China, and the COVID-19 pandemic. Against this background, we maintain that sovereignty discourses function as a self-legitimising protective mechanism of states confronted with challenges from their external environment (Kratohwil, 2006).

In this context, we have argued that technology sovereignty will become an additional, horizontal rationale for innovation policy, supported by trade, investment and competition policies as needed. Increasingly fierce technology-based global competition means that a limited number of countries or economic blocs are fighting for dominance of the ubiquitous key enabling technologies of the future. In contrast to the competition of the post-war period, it is now linked to

serious rivalry between different political and value systems, and is thus assuming a new quality. If this central premise is correct, it is essential that technology sovereignty policies are conceived as supporting the ambition to retain agency in the innovation domain, based on a conceptual expansion to include the notions of risk and vulnerability, rather than as a move towards across-the-board independence, let alone autarky.

Our technology sovereignty concept is therefore built on four central premises:

- First, it is a reaction to a changing world order, in which the preferable system of free trade and international collaboration has come under attack and therefore no longer provides a reliable basis in all circumstances.
- Second, it is a dynamic concept, focused on building competences and capacities through innovation policy and seeking to maintain stable international technological interdependencies wherever possible.
- Third, it highlights the need to not forfeit competences and stability for the sake of short-term profit maximisation without acknowledging the long-term need for agency in critical technologies.
- Fourth, it retains the option to react by activating competition, trade or investment policy instruments as needed, but only as a last resort, possibly in coordination with other countries in the wider context of trade agreements and with a view to retracting those measures as soon as possible to avoid a vicious circle of protectionism.

Applying this enlightened concept of technology sovereignty through state intervention is associated with a number of challenges that are worth highlighting in conclusion. First of all, any technology sovereignty policy will lead to contestation between different economic and societal actors. Inevitably, policies aimed at achieving technology sovereignty will lead to tough choices between strong material interests in society and the economy. In this context, some may be tempted to adopt sovereignty as a normative ideal, with obvious risks. Such a rationale would tilt the entire discourse towards inward-focused protectionist tendencies and autarky, setting in motion a vicious circle internationally, despite the overwhelming body of evidence on the overall superiority of rules-based systems and international openness in science and technology.

A further concern is the internal race for state support of specific technologies under conditions of asymmetric information. Even if state actors follow sophisticated analytical and methodological steps as outlined here and in more detail in Edler et al. (2020), it is still likely that the information advantage of industrial actors in terms of understanding the technology and its international position will induce opportunistic rent-seeking. This problem is exacerbated if the technologies deemed critical for socio-technical transitions multiply and many aspects of the process are normatively charged. Any multiplication of the technologies deemed critical that is not warranted by objective analysis would be an undesirable outcome of the technology sovereignty discourse. The static and dynamic welfare losses could be substantial if preferential treatment is associated with market dominance and the power to mobilise public support rather than the analytical, objective determination of criticality.

In order to limit the risk of welfare losses, it is imperative that the state maintains a sufficient level of independence of actors with vested interests and that it reduces asymmetric information by establishing suitable and capable bodies and/or building capacity in existing ones. This implies - as outlined above - that the state strengthens investments in the ability of the system to understand future needs and technologies, and its own technological expertise by upgrading strategy departments and supporting them with independent expertise potentially even institutionalised in advisory bodies that have no vested interests in the assessed technologies.

The innovation policy of the future will have to be developed in the light of the critical importance of preserving technology sovereignty as a

⁹ https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm.

means for national competitiveness and transformational ambitions. The movement towards mission- and transformation-oriented policies has already complicated innovation policy, but technology sovereignty considerations add to this complexity in terms of the analytical requirements, the political negotiations needed, and the instrumentation of policy itself. Innovation policy which seeks to contribute to a positive development of competences, capacities, systemic conditions and international scientific cooperation, will be complemented to a greater degree than before by trade, investment and competition policies so that it can react more swiftly to the policies of other countries or blocs. Innovation policy therefore faces two challenges: the need for more systemic long-term thinking to secure future technology sovereignty, and more comprehensive short-term reaction, if necessary via other policies, which complicates the coordination and consequently governance of the rather more independent policies. As we have tried to argue throughout, this new, balanced innovation policy must avoid throwing out the baby of international welfare gains through free trade and division of labour with the bathwater of short-sighted technology sovereignty policies driven by domestic interest groups. This is what the concept of agency and structuration tells us. Any action at home to retain or regain agency will inevitably influence international structures. Understanding this structuration may be one of the major requirements of intelligent technology sovereignty policy in years to come.

As a caveat, our conceptual analysis has not covered all dimensions. For example, we did not explicitly consider the size of the economy. So far, we made the implicit assumptions that the economy under analysis has the capacity and therefore the size to be at the leading competitive edge at least in some areas, which allows developing some reciprocal interdependencies with other economies of similar size. However, the smaller countries are, the less they have the opportunity to be leaders in selected technologies and the more they have to find other ways to secure their technology sovereignty, e.g. within a confederation of states or a strong, trustworthy bilateral relationship with a large country based on the same social and economic values. In summary, the size of the economy and the portfolio of technologies that we focus on has to be considered in the analysis of its technology sovereignty. Further, we have not focused on the role of firms. Ensuring the availability of inputs to deliver technologies is first and foremost a managerial task. The division of responsibility between firms, the economy as such and state actors would need further consideration. Nevertheless, with the conceptual framework delivered in this paper, we hope to support a future research programme in our community that rises up to the task posed by geopolitical and geo-economic turbulence.

CRediT authorship contribution statement

Jakob Edler, Knut Blind, Henning Kroll, Torben Schubert: Conceptualisation, Writing Original Draft, Writing Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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