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Technological Sovereignty as Ability, not Autarky

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Abstract

Aspirations towards technological sovereignty increasingly pervade the political debate. Yet, an ambiguous definition leaves the exact goal of those aspirations and the policies to fulfill them unclear. This leaves room for partly particularly negative interpretations, such as equating the concept with a strive for autarky, nationalism, and the roll-back of globalization. We develop a competence-based definition of technological sovereignty, which puts innovation policy at the core of fulfilling sovereignty aspirations. Moreover, we show how our definition realigns technological sovereignty with international cooperation and trade. Two case studies illustrate how innovation policy might be used to achieve technological sovereignty.

Keywords: Technological Sovereignty; Innovation Policy; International Cooperation; Industrie 4.0; EUV Lithography

JEL classification: O32; O33; O38

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1 Introduction

"Technological sovereignty" increasingly permeates the political and public debate. Though this seems to be a recurring issue (see e.g. Grant, 1983, Darnis, 2020a), the debate has recently been fueled by the Snowden affair and the revelations of foreign surveillance in its wake (Maurer et al., 2014), the release of the strategy "Made in China 2025" elucidating China's aim for global tech leadership (Zenglein and Holzmann, 2019), the escalating confrontation between China, the U.S., and Europe regarding Huawei and its role in building 5G telecoms infrastructure (Economist, 2020a), and the Covid-19 crises with the limitations in the supply of face masks, vaccine and pharmaceuticals worldwide (see e.g. Darnis, 2020b, or the special issue of the *Journal of Supply Chain Management* introduced by Flynn et al., 2021).

Technological sovereignty has now found its way into official government programs and strategies, most notably the political guidelines and strategies for data and Artificial Intelligence of the new European Commission (von der Leyen, 2019, 2020, European Commission, 2020), and the "National strategy for critical and emerging technologies" published by the late Trump administration (The White House, 2020). Concomitantly, the public debate has expanded sharply in recent months with various policy papers and opinion pieces attempting to provide own definitions, analysis, and recommendations on the topic (see e.g. DiEM25, 2019, Kagermann and Wilhelm (eds)., 2020, Bauer and Erixon, 2020, BusinessEurope, 2020, Fraunhofer ISI, 2020, Foreign Policy, 2020, Science|Business, 2020).

One problem of the debate is the lack of a common understanding and definition of technological sovereignty. Several parties therefore equate it with a quest for autarky and the re-regionalization of supply chains, and therefore view it as a serious challenge to free trade (see e.g. Dohse et al., 2019, Foreign Policy, 2020, Science|Business, 2020).[1] Many other stakeholders dissociate themselves from this perspective (e.g. BusinessEurope, 2020, Fraunhofer ISI, 2020).

In this discussion paper, we develop a definition of technological sovereignty from prevalent understandings of (political) sovereignty, and relate the two to each other as well as to economic sovereignty. We argue that technological sovereignty of a polity (or society) comprises the set of competences necessary to identify, understand, assess, develop, advance, produce, use, and incorporate those key technologies with largest impact on its political and economic sovereignty, as well as the aspiration to acquire those competences. As a consequence, research, education, and innovation policy are at the heart of strengthening technological sovereignty. Although policies to regulate new technologies and protect them from foreign access may also be important in this regard, they

[1] This sometimes goes by the term "Tech Nationalism", see EastWest Institute (2020), Forbes (2020).

are not sufficient to achieve sovereignty. Moreover, we show that our approach aligns technological sovereignty with international cooperation and free trade and suggests that the two are in fact mutually dependent. Finally, we present short case studies to show how an integrative innovation policy approach can strengthen technological sovereignty in practice.

The paper is structured as follows: In Section 2, we derive definitions of political and economic, and in turn technological sovereignty. In Section 3, we discuss the role of the state in strengthening technological sovereignty. Section 4 discusses the relation between technological sovereignty on the one hand, and international cooperation and trade on the other. Section 5 presents our case studies. Section 6 concludes.

2 Definitions

Though various definitions for technological sovereignty have been proposed in the ongoing debate (see e.g. Fraunhofer ISI, 2020, VDE, 2020), none of them relates the concept to prevalent understandings of (political) sovereignty. We aim at filling this gap to flesh out the relationship between technological, political, and economic sovereignty, and to derive the role of the state in strengthening technological sovereignty.

2.1 Political and economic sovereignty

Political sovereignty (or *state sovereignty*) is, and always has been, a contested concept (see e.g. Kalmo and Skinner, 2010, Costa Lopez et al., 2018). Discussions concern e.g. the origins, the elements, and the scope of the concept. For example, while most scholars trace back the concept to the writings of Bodin (1992 [1576]) and Hobbes (1996 [1651]) and the Peace of Westphalia (1648), elements have been present as early as the Middle ages, and the concept has been refined and sharpened until (at least) the end of the nineteenth century (see e.g. Costa Lopez et al., 2018). Following Krasner (2007, p.1), we take the following definition of political sovereignty as a starting point:

Definition 1. *A political entity (or* polity*) is* politically sovereign*, if (i) there exists a decision-making structure within the entity that has final authority and is legitimated and effective, and (ii) the political entity and its associated authority structure are independent from external control and interference.*

Several comments on this definition are in order:

- First, the authoritative decision-making structure is usually referred to as the *state*, the *sovereign*, or the *government*, and we will follow this notion.
- Second, the definition captures the two most common notions of sovereignty, namely (i) *internal* (or domestic) sovereignty, and (ii) *external* (or international) sovereignty (see

Krasner, 2007). The literature distinguishes several other meanings of sovereignty. In particular, *interdependence sovereignty* "refers to the ability of states to control movement across their borders" (Krasner, 2001, p.19), e.g. of goods, capital, people, or ideas. This concept is therefore heavily related to the territorial view on sovereignty (see below). Furthermore, it is often pointed out that external sovereignty presumes the recognition of the state by other states. This mutual recognition is sometimes referred to as *international legal sovereignty*, and it comprises the ability of a political entity to enter into contractual agreements with other political entities (see Krasner, 2001, p.21). While we sometimes refer to interdependence sovereignty, we largely leave aside the issue of international legal sovereignty, as it constitutes a *de jure* property (see below).

- Third, several scholars view sovereignty as a strictly legal concept, to be distinguished from questions of empirical reality (see e.g. James, 1986, Troper, 2010). As a consequence, sovereignty would be a binary concept: A political entity would either be sovereign, or not at all. Distinctions between different degrees of sovereignty or attempts to strengthen it would be void (see e.g. Kalmo, 2010, Berg and Kuusk, 2010). By contrast, we take the perspective that sovereignty is very much an empirical question, determined by a state's factual abilities, and that different degrees of sovereignty can be distinguished (see e.g. Agnew, 2005, Berg and Kuusk, 2010). In particular, as argued by e.g. Buchanan (1975), the preservation of liberty and welfare requires a *protective state* who enacts and enforces laws and thus requires the necessary capacities to do so (see Acemoglu and Robinson, 2019, Ansell, 2019, Holcombe, 2020 for recent discussions of this issue). Moreover, standards, norms, and even new laws frequently arise out of established practices which is why the ability to shape such practices is another important determinant of sovereignty.

- Fourth, it has been debated whether a bounded territory is an essential element of political sovereignty. Though most scholars take this for granted, recent studies cast doubt upon this view (see e.g. Agnew, 2005). This is particularly important in the discussion of technological sovereignty, as new technologies frequently foster globalization and challenge established state boundaries. For example, the internet crosses state boundaries and thus seems to be antithetical to territorial notions of sovereignty (see e.g. Mueller, 2020). Though we propose below a notion of technological sovereignty that can in principle apply to any collective, regardless of its territorial scope, we also note that the construction of polities is subject to a considerable debate both in politics and economics (see e.g. Näsström, 2003, Alesina, 2003).

- Fifth, we follow the common democratic understanding of political sovereignty as *popular sovereignty*, i.e. sovereignty which "resides in the political will or consent of the population of a territory" (Jackson, 1999, p. 444; see also Przeworski and Wallerstein, 2001, Floridi, 2020). This implies that sovereignty depends not only on the abilities of the state or government in a narrow sense, but also on the competences of the (members of the) polity or society it represents. It also implies that the legitimacy and effectiveness of the state derive from the support of the constituents expressed in democratic processes.[2] Moreover, popular sovereignty provides a link between the sovereignty of political entities and James M. Buchanan's concept of *individual sovereignty*. Accordingly, "only individuals choose and act" (Buchanan, 1987a, p. 4), they are "the ultimate sources of value" (ibid., p. 4) and "the ultimate sovereigns in matters of social organization" (Buchanan, 1991, p. 228).[3] Therefore, "the normative criterion should be one of *opportunity*", i.e. "to set up institutions that give individuals as much opportunity as possible to do whatever they want to do" (Sugden, 2018, p. 34; see also Sugden, 2004).[4]

Based on the above considerations, we propose a second, wider definition of political sovereignty addressing abilities as means to achieving sovereignty.

Definition 2. *Political sovereignty is the ability of a polity to self-determinedly resolve collective action problems.*

This second definition expresses political sovereignty as a straightforward extension of individual sovereignty, understood as freedom of choice. Moreover, it highlights a polities' ability to develop mechanisms or institutions able to resolve group-decision problems like enacting and enforcing laws, providing public goods, or managing renewable resources given the individual preferences of the polity's members. The state as defined above is then the institution implementing the group decision.

Turning back to the legitimacy of the state, it is commonly agreed that this hinges upon the lasting performance of its duties. According to Hobbes (1996 [1651], p. 231), "The Office of the Soveraign [...] consisteth in the end, for which he was trusted with the Soveraign Power, namely the procuration of the safety of the people; [...]. But by Safety here, is not meant a bare Preservation, but also all other Contentments of life, which every man by lawfull Industry, without danger, or hurt to the Common-wealth, shall acquire to himselfe.". Hence, one of the duties of the state is the preservation of the welfare of the polity (see also Skinner, 2010, p. 28). Thus:

[2]This is not to say that legitimacy and effectiveness of the state are superfluous in non-democracies. However, challenging established institutions and claiming legitimate and effective governance is likely to be harder in this case.

[3]See Sugden (2018) and Vanberg (2020) for general discussions of the concept, Buchanan (1985) for a link to democratic theory, and Buchanan (1988) for a discussion of the relation between individual and *consumer sovereignty* (Hutt, 1940, Persky, 1993).

[4]Notice that institutions are understood broadly here and also capture, e.g., the regulatory framework.

Definition 3. *Economic sovereignty is the ability of the state to foster the economic interests of its polity.*

Economic sovereignty is political sovereignty applied to economic policy (see also Quiggin, 2001, Richardson and Stähler, 2019), but it is also an important element and premise of political sovereignty.

2.2 Technological sovereignty

Having defined both political and economic sovereignty, we next turn to the impact of technologies on these two properties. Concretely, we posit that technologies[5] consistently change and challenge the political and economic sovereignty of a polity. This holds, in particular, for *key enabling technologies (KETs)* (as defined by European Commission, 2009, 2012, 2018) or, closely relatedly, *general purpose technologies (GPTs)* (see e.g. Bresnahan and Trajtenberg, 1995, Bresnahan, 2010) which are characterized by broad applicability across the economy, high R&D and skill intensity, fast and ongoing improvements, and innovational complementarities, i.e. enabling and being enabled by innovations in various application sectors.[6] Subsequently, we call key enabling technologies just technologies in short.

We distinguish eight main effects of technologies on sovereignty:

- First, and evidently, economic progress and prosperity are driven by technological change (see e.g. Acemoglu, 2009, Jones, 2019). This holds particularly for developed countries with a built-up capital stock, and a meek or negative population growth. Maintaining and strengthening economic sovereignty therefore require the mastery and constant advancement of existing, and the recurrent discovery of new technologies.

- Second, new technologies create new policy fields. The regulation of artificial intelligence is as novel today as data policy in the 1970s, energy policy in the 1920s, telecommunication policy at the beginning of the last century, or cyberspace/Internet policy at the end of that century. In addition, new technologies may widen what is understood as essential public infrastructure to be provided by the state. In the past years, broadband and mobile phone networks have become as vital as railway networks or gas and water supply. Infrastructures for high-performance computing, data provisioning and exchange, or the storage, transport, and conversion of green hydrogen are about to join this set.

[5]

[6]Though a complete list of KETs or GPTs is unavailable, the classification of the European Commission (2018) comprises photonics, micro- and nanoelectronics, advanced materials and nanotechnology, Life Sciences technologies, advanced manufacturing technologies, artificial intelligence, and digital security and connectivity, and we would definitely add data and quantum technologies to this list.

- Third, new technologies foster globalization. This not only holds for new information and communication technologies (*ICT* henceforth, see e.g. Steele and Stein, 2002), but also for advances in transportation technologies like railways or container ships. A general postulate of the political-economic literature is the incompatibility of globalization and political sovereignty of democracies.[7] More specifically, increasing globalization enhances the scope of political decisions which is why a polity is increasingly influenced by political decisions made elsewhere. This challenges the very heart of political sovereignty. One prominent example is the free flow of data through cyberspace which implies that data regulations for one polity (like the U.S.) may spill over to other areas and polities. Moreover, such global spaces are often, at least initially, regulated by private actors as their sovereign regulation requires international cooperation and agreements, and the sovereignty-based international order is often ill-suited to quickly deliver such agreements (see Steele and Stein, 2002, Drezner, 2004). As a consequence, some scholars deny the applicability of political sovereignty to cyberspace altogether (see e.g. Mueller, 2020). While history shows that states may close the regulation gap over time, if they desire to,[8] other historical examples like the Snowden revelations or the current Internet policy of e.g. China and Russia indicate that states frequently prefer to enforce their own sovereignty, sometimes even at the expense of other polities' (external) sovereignty. Fostering the necessary international agreements thus requires the quick identification of new globalization-enhancing technologies, and the buildup of the necessary capacities to be recognized as a partner on eye level.

  Another consequence of an increasingly globalized world is the difficulty of public good provision. Indeed, the benefits of public goods such as Internet infrastructure may go far beyond the constituency financing them. Accordingly, novel financing mechanisms may be necessary which rely on an understanding and (potentially) use of the new technologies.

- Fourth, new technologies shift power to private actors, especially corporations. After all, it is companies who "*design*, *produce*, *sell*, and *maintain*" technologies (p. 371, emphasis in original Floridi, 2020). Companies may use the resulting knowledge advantage over states to establish their own rules in new fields of regulation (see above), and thus create precedents that are hard to evade subsequently. The classic examples are platforms who exploit regulatory gaps to use their customers' data to their advantage (see e.g. Zuboff, 2019). Firms also have decisive roles in the definition of technological standards. On the one hand, many standards are *market-based* as they result from the success of a single technological solution in market compe-

[7]This is sometimes referred to as the *great trilemma*, see Stein (2016).
[8]See e.g. Drezner (2004), for two case studies in the context of the Internet.

tition (see e.g. Tassey, 2000, Narayanan and Chen, 2012, Wiegmann et al., 2017). On the other hand, firms also strategically act in standard-setting organizations to ensure that their patents are included in committee-based standards (see e.g. Kang and Bekkers, 2015). Current trends suggest that standards are likely to increasingly result from multi-mode standardization processes which combine market forces, committees, and government regulation (see Wiegmann et al., 2017).

In addition, new technologies may be used to circumvent existing regulations in novel and unanticipated ways. For instance, the common requirement of a physical presence in tax laws opens up new opportunities of tax evasion for digital companies (see Li, 2015). Platform work provides novel challenges for labor market policies (see e.g. Pasquale, 2016). The blockchain may make many central state functions, like monetary policy, obsolete (see Manski and Manski, 2018). Addressing these challenges not only requires technological know-how on the part of the state. At least equally important are competitive domestic companies which may disseminate domestic standards and regulations.

- Fifth, new, especially digital technologies are often characterized by strong network effects and economies of scale which leads to winner-take-all-markets and monopolization (see e.g. Shapiro and Varian, 1998, Mazzucato, 2018a). This arguably limits product variety and citizens' choice opportunities, and may thus restrict a polity's ability to acquire the technology specification that best implements its agreed upon values.

- Sixth, new technologies may change foreign dependencies of polities. One example are new infrastructures mentioned above whose components might have to be imported, if their base technologies are not available. The discussions around the incorporation of Huawei equipment into European 5G networks are but one prominent example. Furthermore, new technologies may change dependencies on natural resources. For instance, ICT and batteries for e.g. electromobility contain considerable amounts of rare earth elements that are difficult to mine and only occur in some places in (economically) minable concentrations (see e.g. Dushyantha et al., 2020). Today, China dominates rare earth production, supplying more than 90% of the global demand. However, new technologies may also decrease such dependencies as in the case of renewable energy technologies and fossil fuels.

- Seventh, new technologies create new security threats. Today, the focus mainly lies on threats imposed by ICT like cyberattacks or new forms of espionage and surveillance. However, climate change or ozone depletion have likewise resulted from technological development. Abilities to advance or redesign technologies to make

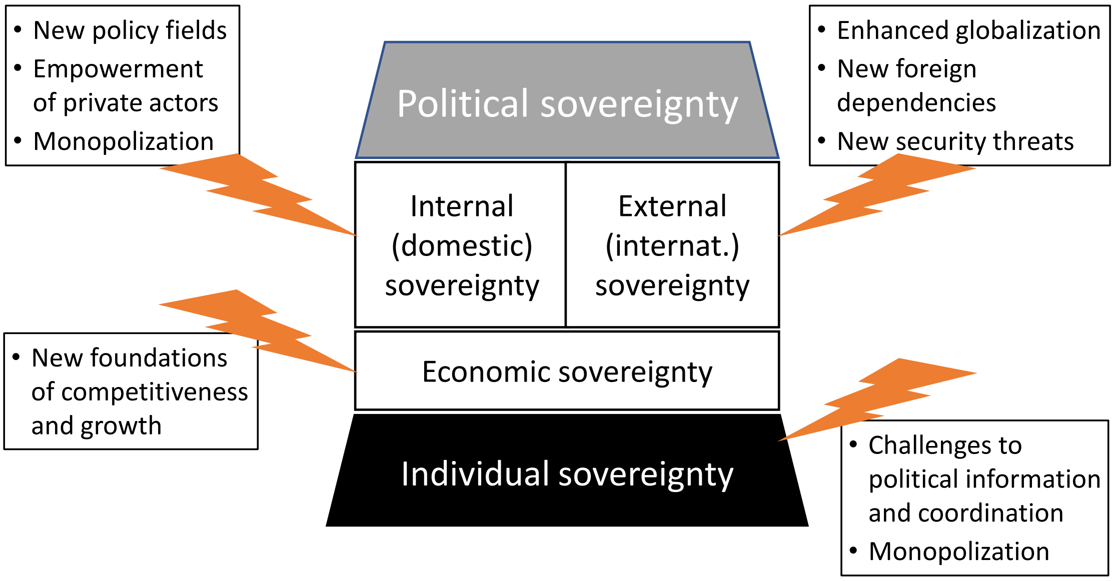

FIGURE 1
How technology challenges sovereignty

them (more) secure and sustainable *by design*, to limit their use, or to continuously develop technological responses to technology-based attacks (a key element of e.g. cybersecurity) are vital to address such threats.

- Finally, new technologies also challenge the foundations of popular sovereignty. In particular, new communication technologies change the political information environment (see Bennett and Pfetsch, 2018). While nowadays, the focus lies on *echo chambers* and *fake news* (see e.g. Del Vicario et al., 2016, Allcott and Gentzkow, 2017), communication technologies have been used to disrupt political communication for centuries, e.g. by propaganda (see Steele and Stein, 2002). In addition, the enhanced globalization brought about by new technologies may change the construction of identities and thus an important element of group cooperation (see e.g. Akerlof and Kranton, 2005, Chen and Li, 2009, Chen and Chen, 2011).

Figure 1 summarizes the various challenges that technologies impose on sovereignty. Jointly, they indicate that the preservation of political and economic sovereignty require a polity to maintain the necessary abilities to identify, understand, assess, develop, advance, produce, use, and incorporate the (key) technologies which drive those changes. We summarize these competences as technological sovereignty:

Definition 4. *Technological sovereignty is the ability of a polity to self-determinedly* shape *the development and use of technologies and technology-based innovations which impact its political and economic sovereignty.*

In a narrow sense, technological sovereignty is the ability to make self-determined decisions about the development and use of technologies and technology-based innovations, especially regarding their properties (e.g. energy consumption, data usage, security, or safety) and their terms of use (e.g. restriction to certain domains, or transparency). In a broader sense, a polity is technologically sovereign, if it possesses the technological abilities necessary to maintain political and economic sovereignty.

Our premise here is the *embedded values approach*, i.e. that technologies embed norms and values which is why the design and not merely the use of technologies has moral consequences (see e.g. Brey, 2010, Miller, 2021). As a consequence, regulating technologies *ex post* is insufficient to preserve political and economic sovereignty. Rather, sovereignty must be defended along the entire technology development chain – from basic research to broad deployment and adoption.

Note finally, how our definition coincides with other definition of technological sovereignty (of a state), e.g. as "the capability and the freedom to select, to generate or acquire and to apply, build upon and exploit commercially technology" (Grant, 1983, p. 240) or as "the ability [. . .] 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" (Fraunhofer ISI, 2020, p. 3). However, none of these definitions are related to economic, political, or legal concepts of sovereignty. This leaves open the question who (in a state) develops and applies technologies.[9] We turn to this issue next by considering the role of the state in the light of the above definition.

3 Technological sovereignty and innovation policy

As technological sovereignty has been included as a goal and guiding principle in various government strategies, a central question concerns the concrete policies to secure and strengthen technological sovereignty. In defining the role of the state, we follow Buchanan (1975) and distinguish between "a *protective state* that preserves people's rights and a *productive state* that produces collective goods" (Holcombe, 2020, p. 371, emphasis added).

The notion of the protective state summarizes the state's responsibility to enact and enforce a political-legal framework that provides for the security of people and property and for the administration of justice, and thus also facilitates the proper working of the market (see e.g. Buchanan and Musgrave, 1999, p. 83f.; Reisman, 1998). Hence, establishing a regulatory framework for new technologies, adapting existing regulations to them, and improving their enforcement are important elements of a policy aimed at maintaining and strengthening technological sovereignty. This may lend support to the recent surge in antitrust litigations against major tech companies in Europe (see e.g. New York Times, 2020) as well as the strengthening of competition law (see e.g. Directive

[9] Grant uses his definition and the distinction between capability and freedom to derive policy options and discuss them in the light of historical examples.

2019/1 of the European parliament and of the council).

However, as argued previously, a focus on regulation alone will be too narrow.[10] First, establishing regulations that do not prohibit the development and use of new technologies entirely – which would stifle their potential with respect to e.g. economic sovereignty – requires in-depth know-how about those technologies. Second, enforcing technology-oriented regulations usually requires abilities to validate their properties, or guide their development in the spirit of the regulatory framework. Indeed, according to the embedded values approach, standards, norms, and laws can often not be implemented *ex post*, but need to be accounted for in the development of the technology. Third, technology-induced threats to e.g. security can often only be prevented or countered by using and advancing the technologies. Thus, research and development (*R&D* henceforth) are necessary for the sovereign protective state.

Complementary, Buchanan's notion of the productive state captures the state's responsibility to produce "collective goods that individuals could not produce on their own or through market mechanisms" (Holcombe, 2020, p. 371), where Buchanan's focus lies on "genuine public goods in the technological nonrivalry sense" (Buchanan and Musgrave, 1999, p. 84).[11] Public investment into R&D of new technologies is a case in point. The public good property of knowledge is well known and a prevalent justification for the public support of (basic) research in particular.

Yet, various of the above arguments suggest that public support of R&D should not be restricted to basic research. The aim to strengthen economic sovereignty, and to support private firms whose products and services implement domestic regulations and standards justify a legitimate interest of the state in successful *technology transfer*. Rather than reiterating possible technology transfer policies and their effectiveness (see e.g. Bozeman et al., 2015, Guerrero and Urbano, 2019, or Bengoa et al., 2020 for recent surveys), we make four specific points:

- First, the state has an important role in overcoming coordination problems which result from network effects and economies of scale. This may require the state to support R&D on own technology variants despite market supply, or even to create markets rather than just correcting them (see e.g. Mazzucato, 2016, Mazzucato and Semieniuk, 2017, Laplane and Mazzucato, 2020). Coordination problems are arguably particularly severe for GPTs due to their innovational complementarities which induce far greater externalities (see e.g. Bresnahan, 2010).

- Second, due to the additional requirements that new technologies put on public

[10] See Grant (1983), p. 252, for a similar argument.

[11] Buchanan frequently provides examples of public goods and services in his work, e.g. the draining of a local swamp (Buchanan, 1964, p. 219f.), and he argues that federalism provides a vehicle of competition for the efficient mix of public goods and services (Buchanan, 1995).

infrastructure and the new challenges they bring along for public security, the state also has an important role on the demand side of innovation (see e.g. Edler and Georghiou, 2007, Guerzoni and Raiteri, 2015, Raiteri, 2018).

- Third, standardization plays an important role for technological sovereignty and should be actively fostered by the state. This involves, e.g., fostering pre-market standardization concomitant with R&D, supporting the building of appropriate consortia, and choosing the right standards regulation (see e.g. Kerstan et al., 2012, Delcamp and Leiponen, 2014, Cabral and Salant, 2014).

- Fourth, the state should also support the formation of appropriate innovation ecosystems (see e.g. Asplund et al., 2021).

As argued above, technological sovereignty comprises a multitude of competences. Obviously, this entails the ability of a polity's members to freely decide over the use of new technologies, and therefore the necessary competences to do so in an informed way. As a consequence, strengthening technological sovereignty requires education policy.[12] Indeed, this extends beyond individual (technological) sovereignty. Human capital is an important determinant of a polity's and society's ability to produce and absorb innovations (see e.g. Faems and Subramanian, 2013, Lenihan et al., 2019, or Martinidis et al., 2021 for recent evidence and further references).

To summarize, our competence-based definition of technological sovereignty straightforwardly implies that research, education, and innovation policy are key to strengthening technological sovereignty. Indeed, what is necessary is holistic innovation policy as also emphasized by recent mission-oriented approaches (see e.g. Kattel and Mazzucato, 2018, Mazzucato, 2018b). Clearly, this also involves regulatory measures. Yet, our point is that a policy focusing mainly on regulation is insufficient to maintain technological sovereignty in the present and future. Moreover, and unsurprisingly given the cumulative and increasingly complex nature of technology development, international cooperation and trade enable and derive from technological sovereignty, rather than being its antithesis. We turn to this in the next section.

Before, we note that civic involvement is an important prerequisite, if popular sovereignty is taken seriously. After all, citizens "ultimately control their own social order" (Buchanan, 1987b, p. 250).[13]

[12] Though Buchanan concurs that education is a legitimate task of the state, he does not put it under the umbrella of the productive state. Concretely, he argues that there is "a legitimacy for some action by collective agency to maintain fairness in the game", and that "educational spending ought to be brought under that rubric rather than any public goods rubric" (Buchanan, 1986, p. 86).

[13] According to Buchanan, this applies first and foremost to "the *constitutional* level, the level at which the *rules of politics* are chosen" (Vanberg, 2020, p. 348). Still, the main purpose of this focus is the reconciliation of unanimity as the sole social choice criterion in line with individual sovereignty with the

4 Technological sovereignty and international trade

The classic trade-based argument against technological sovereignty interprets it as a strive for autarky, and refers to Ricardian and Heckscher-Ohlin models of international trade to show how this negates the substantial welfare gains from the international division of labor. By contrast, we argue that technological sovereignty on the one hand, and international cooperation and free trade on the other are indeed mutually dependent. Accordingly, technological sovereignty is an important determinant of welfare-enhancing international trade, and international trade and cooperation facilitate technological sovereignty. In a nutshell, we therefore posit that technological sovereignty can and should be reached through international cooperation.

Our argumentation is based on two pillars: First, the competence-based definition of technological sovereignty clearly distinguishes it from a strive for autarky. The ability to understand, advance, or produce new technologies must not be confused with the attempt to actually do so in all key enabling technologies and/or components. Instead, we understand it as a widening of choice opportunities, and as a prerequisite for international trade "on eye level". Moreover, we see capacities to innovate as a key to achieving technological sovereignty. Second, we rely on more advanced approaches to international trade which take into account factors that Ricardian trade models are mostly silent about. This includes, e.g., the terms of trade and their determinants, the origins and dynamics of comparative advantage, and incomplete or asymmetric information in trade relationships. These points enable us to rely on a large and growing theoretical and empirical literature that supports a "bi-causal" relationship between our competence-based view on technological sovereignty, and international trade and cooperation (Greenaway and Kneller, 2007, p. 145). Below, we summarize this literature with a focus on five potential links between the two areas. A summary is provided in figure 2.

4.1 Technological sovereignty creates comparative advantage

The *neo-technology approach to international trade* posits that comparative advantage and trade flows are determined by countries' technological capabilities and the *technology gap* between them. Following the seminal papers by Posner (1961) and Vernon (1966), various models theoretically explore the implications of this approach (see e.g. Krugman, 1979a, Dollar, 1986, Grossman and Helpman, 1991a). The basic assumption is that new technologies are initially offered only by a few highly developed countries. Several justifications have been put forward for this assumption: First, new technologies and technology-based innovations stem from research and development (R&D) activities. Second, a higher aver-

difficulty of reaching agreement on concrete policy issues in a large constituency (cf. Vanberg, 2020, p. 349). Hence, citizen involvement on concrete policy issues may be justified as well – and may well involve majority rule (cf. Buchanan, 1986).

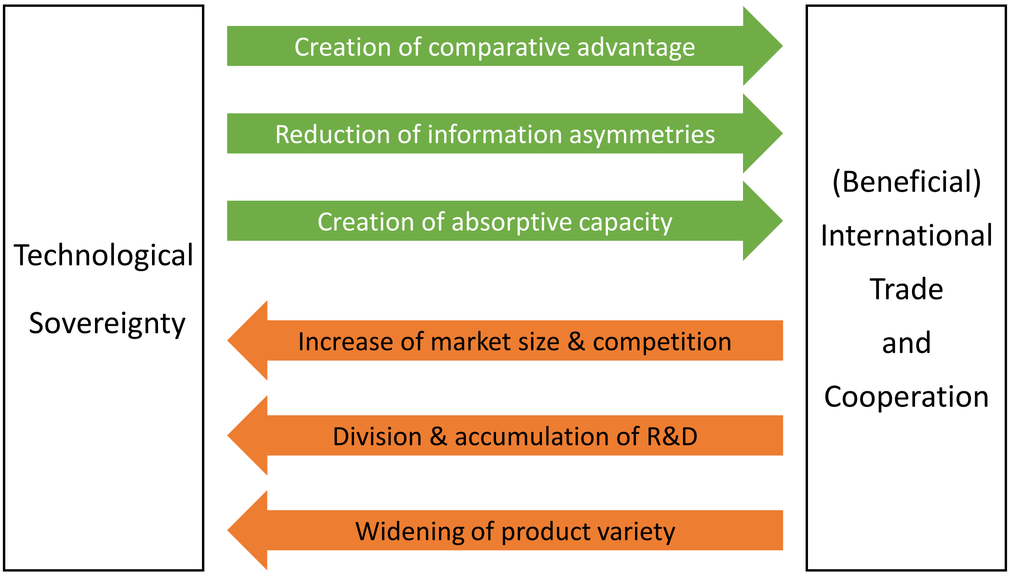

FIGURE 2
THE BI-CAUSAL RELATIONSHIP BETWEEN TECHNOLOGICAL SOVEREIGNTY AND INTERNATIONAL COOPERATION

age income induces a larger domestic demand for new technologies and technology-based goods and services which in turn implies a better communication between the demand and supply side of the market and is thus more conducive to successful R&D (cf. Vernon, 1966, p. 192f.). Third, higher labor costs put a larger pressure on firms to reduce costs and thus invest into R&D (ibid.). Fourth, a more skilled labor force is more favorable to R&D (cf. Krugman, 1979a, p. 255f.).

Over time, imitation and technological spillovers enable further countries to also produce the new goods and services, and to do so less costly due to e.g. lower wages and more favorable labor market regulations. This puts pressure on the developed countries to reach the next technology level. A *product cycle* results in which technologies, products, and services are continuously improved and imitated, and offered by different countries at different points in time (cf. Wells, 1972). More advanced models show that this process not only leads to a specialization of the highly developed countries on technology-intensive sectors and firms and a corresponding structural change of the industry (see e.g. Melitz, 2003), but also to higher wages and welfare gains (see e.g. Acemoglu and Ventura, 2002).

The above models have stimulated a large and growing empirical literature which clearly confirms the impact of technological capabilities on exports (see e.g. Dosi et al., 1990, 2015, Andersson and Ejermo, 2008, Bayar, 2018). R&D and the corresponding increase in technological capabilities not only increases the propensity to export and the volume of exports, but also the fraction of technology-intensive goods and services and their quality. This holds at the country, the sectoral, and the firm level (cf. Dosi et al., 2015), and for various indicators. Indeed, know-how in ICT increases not only the export share in the ICT sector but also in non-ICT industries (see Laursen and Melicani, 2010, Wang and Li, 2017).

The neo-technology approach to international trade justifies a view of technological sovereignty not as an antithesis but as a prerequisite of international trade and the associated welfare benefits. Strengthening technological sovereignty is then particularly important for highly developed and export-oriented countries, and an important ingredient of trade policy.

4.2 Technological sovereignty reduces asymmetric information

Trade is often plagued by asymmetric information between the trading parties regarding e.g. the quality or other properties of a product or technology. The economics of information has long established that such information asymmetries lead to a shift in the terms of trade in favor of the informed party, and to trade inefficiencies in the form of higher transaction costs, lower quality of the exchanged goods, or even a complete breakdown of trade (see Stiglitz, 2000, for an overview). Two main issues are *adverse selection*, i.e. the tendency to trade low quality goods (cf. Akerlof, 1970), and *moral hazard*, i.e. the incentive for the informed party to behave opportunistically (cf. Arrow, 1971).

Clearly, information asymmetries and their consequences also affect international trade. Indeed, they tend to be even more severe when goods cross national borders (see e.g. Dalton and Goksel, 2013, Dasgupta and Mondria, 2018). Again, the consequences may involve *inter alia* an (additional) information cost of trade (Dasgupta and Mondria, 2018), restrictions of the range of available qualities (Cagé and Rouzet, 2015), informational barriers to entry of domestic firms (see Grossman and Horn, 1988, Chen, 1991), and even the partial or complete breakdown of international trade (Rauch and Casella, 2003). This in turn increases the importance of reputation mechanisms like national brands, and institutions like trade intermediaries and trade networks which may remedy information asymmetries, but possibly induce new frictions (see Rauch, 2001, Rauch and Casella, 2003, Chisik, 2003, Bardhan et al., 2013, Cagé and Rouzet, 2015, Dasgupta and Mondria, 2018).

Strengthening technological sovereignty may reduce such information-based frictions of international trade. Indeed, improving competencies to e.g. certify the quality of imported components will lower problems of adverse selection and moral hazard. Quality standards can help in this regard (see e.g. Donnenfeld et al., 1985, Cagé and Rouzet, 2015). Second, fostering R&D can support market entry by domestic forms (see e.g. Chen, 1991, Chisik, 2003). Third, R&D networks in which reputation has already been built may serve as a basis for trade networks. Finally, an improvement in contracting institutions improves both the advancement of technology and the terms of international trade (Acemoglu et al., 2007). In a nutshell, technological sovereignty enables international trade on eye level.

4.3 Technological sovereignty generates absorptive capacity

Technological sovereignty not only facilitates exports. It is also a prerequisite for welfare-enhancing imports. To wit, the innovation economic literature has emphasized the importance of firms' *absorptive capacity* (cf. Cohen and Levinthal, 1989, 1990, Nelson and Pack, 1999), i.e. the "ability to identify, assimilate, and exploit knowledge from the environment" (Cohen and Levinthal, 1989, p. 569), and the role R&D may play in creating it. Concretely, own R&D serves three purposes (see Cohen and Levinthal, 1989, 1990): First, it enables a firm to adapt R&D results from the outside to its specific field of application and put them to (commercial) use. Second, R&D is necessary to identify and understand relevant R&D results in the first place, and combine them with own knowledge. A concrete example is the integration of imported technology components into complex systems. Third, the better a firm's own R&D the better it may account for technological spillovers.

Empirical studies confirm the importance of absorptive capacity based on own R&D. Nelson and Pack (1999) argue that "the absorption [...] of increasingly modern technology and the change in industrial structure has been the critical component" in the rapid growth of Asian economies in the second half of the twentieth century (p. 416). Liu and Buck (2007) show that Chinese firms with a higher level of absorptive capacity in the form of R&D manpower or infrastructure benefit more from foreign technology spillovers. Andersson and Ejermo (2008) establish that the quality of exported products also depends on the technology specialization of the destination country. Finally, Das (2002) argues that "a better-educated workforce is beneficial for effective assimilation of foreign improvement of technology" (p. 258).

In summary, the literature suggests that technological sovereignty interpreted as the knowledge about new technologies mediates the benefits from importing. This necessitates not only the promotion of own R&D, but also an efficient educational system.

4.4 International trade and cooperation strengthen technological sovereignty

The neo-technology approach to international trade focuses on the impact of R&D and innovation capacity on exports. Early on, the literature has also emphasized a potential reverse relationship according to which international trade facilitates domestic R&D and innovations (see e.g. Keesing, 1967, Hughes, 1986, Segerstrom et al., 1990, Grossman and Helpman, 1991b). Different channels may support such a reverse causality: First, international trade increases the size of the market and thus the returns to R&D (cf. Hughes, 1986, Aw et al., 2011, Baldwin and Yan, 2012). Second, it also increases competition and thus incentives to innovate (cf. Hughes, 1986, Lall, 1992). Third, the associated international division of labor enables to conduct R&D and develop new technologies where this can be done most efficiently, and to distribute resources (e.g. scientists, professionals) accordingly (cf. Segerstrom et al., 1990, Grossman and Helpman, 1991b). Finally, international trade provides access to knowledge, technologies, and innovations that can form the basis for new developments (cf. Lall, 1992, Evenson and Westphal, 1995). As discussed above, this *learning-by-exporting* rests upon a firm's absorptive capacity. Jointly with the evidence presented above, the literature suggests that technological sovereignty does not only facilitate international trade, but is also fostered by it. This bi-causal relationship may give rise to a mutually reinforcing dynamic and a corresponding structural change within an industry (cf. Melitz, 2003, Helpman, 2006).

Turning to empirical studies, we note first that early tests find only weak support for such a bi-causal relationship, and a much stronger causality from technological abilities to trade (see Greenaway and Kneller, 2007, for a survey). However, more recent studies find strong support for the opposite causality as well (see e.g. Lachenmaier and Wößmann, 2006, Liu and Buck, 2007, Verhogen, 2008, Siedschlag and Zhanga, 2015, Bloom et al., 2016, Chen et al., 2017).[14] Hence, international trade fosters technological sovereignty.

More broadly, technological sovereignty not only benefits from international cooperation, but increasingly depends on it. Indeed, science has become more and more collective and international in recent years (see e.g. Wuchty et al., 2007, Elzinga, 2012, Hsiehchen et al., 2015, Bozeman and Youtie, 2017). One reason is the increasing importance of large research infrastructures whose costs are too large for one country alone while their benefits are characterized by large externalities (see e.g. Castelnovo et al., 2018, D'Ippolito and Rüling, 2019). Moreover, the trend towards specialization and interdisciplinarity in science, and the greater opportunities for and falling costs of communication and transport foster this dependency (cf. Katz and Martin, 1997).

4.5 International trade increases product variety

One empirical fact that is particularly hard to explain by Ricardian trade models is the large fraction of international intra-industry trade. Its prevalence has increased considerably in the second half of the twentieth century and stabilized on a high level since then (cf. Melitz and Trefler, 2012). To explain these facts, a new trade theory has developed in the 1980s based on four core assumptions: economics of scale, network effects, imperfect competition, and product differentiation (see e.g. Krugman, 1979b, 1980 and Helpman, 2011, chapter 4). Besides explaining the considerable amount of intra-industry trade, these models also predict that the latter increases product variety. Empirical studies clearly confirm this prediction, and they show that an increase in product variety leads to higher consumer welfare (for final goods, see e.g. Broda and Weinstein, 2006, Feenstra,

[14]The focus in many of these studies is on firms' productivity. Still, a relation to technological sovereignty may straightforwardly be derived.

2010), and a higher productivity (for intermediates, see e.g. Amiti and Konings, 2007, Goldberg et al., 2010, Halpern et al., 2015).

Recall that the definition of technological sovereignty presented above is closely related to individual sovereignty, which can be understood as the self-determination of individuals regarding, in particular, the properties of technologies and technology-based innovations they want to use. Arguably, a greater product variety increases individuals' opportunities, and thus their sovereignty (cf. Sugden, 2004). This is the final sense in which international trade fosters technological sovereignty.

5 Case studies

Above, we emphasize that strengthening technological sovereignty requires an integrative policy approach, with education and innovation policy at its core, and international cooperation as an important ingredient. Here, we provide two short case studies to demonstrate how such a policy approach may work in practice.

5.1 Industrie 4.0 – Towards technological sovereignty in manufacturing

Industrie 4.0 as a concept and a target for innovation policy was launched in 2011 when the German government officially announced the start of a future project (or strategic initiative) suggested by the *Industry-Science Research Alliance*, an advisory body accompanying the implementation of the high-tech strategy (see Kagermann et al., 2011, and see Reischauer, 2018 and Oztemel and Gursev, 2020 for recent surveys). The starting point of the future project Industrie 4.0 was the strength of the German manufacturing sector on the one hand, and the foreseeable technological changes challenging this position on the other. This involved, in particular, the rise of so called *cyber-physical systems*, the digitalized interconnection of devices, machines, buildings, and other infrastructures with each other, of products and services and with human actors. The ability of those connected devices to communicate with each other as well as to record and process data increasingly enables the self-regulation of production facilities. Maintaining technological sovereignty in the field of cyber-physical systems (though the term was not referred to explicitly) was thus seen as crucial for maintaining competitiveness of the manufacturing sector, and thus as a key ingredient of economic sovereignty.

The German government has since then followed a holistic policy approach in pursuing this initiative, in cooperation with central stakeholders from science, industry, and civil society. In 2013, a working group from the Industry-Science Research Alliance published its recommendations for implementing Industrie 4.0 (Kagermann et al., 2013). This involved, in particular, recommendations on research, standardization, necessary infrastructures, training and professional development, and the regulatory framework. At the same time, the German interest groups Bitkom (Association for Information Technology, Telecommunications, and New Media), VDMA (Mechanical Engineering Industry Association), and ZVEI (Electrical and Electronic Manufacturers' Association) launched the "Platform Industrie 4.0", an industry-led network to support and monitor the implementation of the recommendations in cooperation with the German Federal Ministry of Education and Research (*BMBF* henceforth) and the Federal Ministry for Economic Affairs and Energy (*BMWi* henceforth; see e.g. Bitkom et al., 2016).

The two ministries have in the past years implemented a host of activities to advance Industrie 4.0 (see e.g. BMBF, 2020). This entails *inter alia* (i) the funding of research, especially on advanced production technologies, smart services, software systems, microelectronics, new communication technologies, and cyber security, (ii) the support of research transfer, e.g. with the build up of innovation labs and test centers, and targeted funding opportunities for small and medium-sized enterprises (*SME* henceforth), (iii) fostering the development of standards and reference architectures, like RAMI 4.0 (see Lydon, 2019), BaSys 4.0 (Perzylo et al., 2019), IUNO (Duque Anton et al., 2019), or the International Data Space (*IDS*, see Otto et al., 2019), and (iv) promoting the development of competences, e.g. in the context of the research program "The Future of Work" (BMBF, 2016). In addition, international cooperation has been an important ingredient of the initiative, both with European partners like France, Italy, the Netherlands, and the Czech Republic, and worldwide, e.g. with Japan, Korea, China, and Mexico.[15] Moreover, Germany has successfully participated in Industrie 4.0 projects funded by FP7, the Seventh European Framework Programme for research and development (see Muscio and Ciffolilli, 2020). Notice, however, that policy initiatives on the enabling technologies of Industrie 4.0 go back way further than 2011. Indeed, the initiative was intentionally built upon Germany's strengths in embedded systems and production technologies (see Kagermann et al., 2013).

Since the start of Industrie 4.0, Germany has been able to maintain the strength of its manufacturing sector which still contributes almost 20% to GDP, more than twice as much as in other European countries like France or the UK, and considerably higher than in the U.S. (source: World Development Indicators, World Bank). Germany also remains the number two exporter of machinery (source: ITC trade statistics). Moreover, it accounts for the third largest share of Industrie 4.0 related patent applications at the European Patent Office, with the highest patent intensity in enabling technologies (see Benassi et al., 2020). Today, the Plattform Industrie 4.0 comprises more than 350 stakeholders. Many countries have followed the German example and implemented Industrie 4.0 initiatives of their own (though not always under this label, see e.g. Kagermann et al., 2016, Liao et al., 2017, Yang and Gu, 2021). These results indicate that Germany has managed

[15] See `www.plattform-i40.de/PI40/Navigation/EN/ThePlatform/Structure-Organization/InternationalCooperation/international-cooperation.html`.

to achieve technological sovereignty in manufacturing (see Horst and Santiago, 2018 for further indicators on the success of the initiative).

Still, the success of Industrie 4.0 is just a snapshot. Many challenges remain. The uptake of Industrie 4.0 technologies is far from complete, especially in SME (Horst and Santiago, 2018, p. 21). Products and services keep melting into a *hybrid value creation*, relegating manufacturing to one of many links in the value chain. The data and platform economy are on the rise and increasingly affect classic industries. In addition, sustainable manufacturing becomes increasingly important. The Plattform Industrie 4.0 has therefore developed a vision for Industrie 4.0 in 2030, based on the three pillars autonomy, interoperability, and sustainability (BMWi, 2019). The project GAIA-X is one of the early outcomes of this vision with its goal "to set up a data and infrastructure ecosystem that is true to European values and standards" (BMWi, 2020, p. 2). Based on the IDS architecture and with a clear European perspective, GAIA-X can be seen as a straightforward extension of Industrie 4.0 (see Braud et al., 2021). In addition, BMBF has launched a new research programme on "The Future of Value Creation" intended to carry Industrie 4.0 into the next decade (BMBF, 2021a). The struggle for technological sovereignty in manufacturing thus continues.

5.2 EUV Lithography – Becoming sovereign in lithography

Microchips always have been one of the most contested technology fields (see e.g. Borrus, 1988). The geopolitical tensions between the U.S. and China over Huawei Technologies and semiconductor exports, and the current chip shortage are only the most recent indicators. Europe seems to be a minor player in this field with a market share in semiconductor manufacturing of only 10% in 2020 (see SIA, 2020), and therefore strong dependencies on suppliers from Asia and the U.S. As a response, the European Union (*EU* henceforth) has recently announced the goal to double its global market share in semiconductor manufacturing until 2030 (European Commission, 2021).

Yet, Europe is global market leader in semiconductor manufacturing equipment: The Dutch company ASML Holding has a global market share of over 60% in the field of photolithographic machines (see Economist, 2020b). It supplies the largest chip manufacturers worldwide, Intel, Samsung, and TSMC, and is in turn dependent on a huge supplier network, mainly from Europe. The competitive advantage to the firm, which is expected to grow even further in the near future, is based on its unique ability to manufacture lithographic machines that use extreme ultraviolet (*EUV*) light. Due to its short wavellengths, EUV light allows to edge structures of less than 10 nanometers in size on silicon wafers. This enables the production of more advanced and more powerful microchips. At the same time, EUV lithography entails many technological challenges, especially the need for an optical system of extremely precise mirrors, and an extremely high-powered light source (see Wagner and Harned, 2010). The suppliers for these two key elements are the German companies Zeiss and Trumpf (Portway, 2021), who were awarded the *Deutscher Zukunftspreis* (German Future Prize, prize of the Federal President for technology and innovation) for their contributions to EUV lithography.

EUV lithography is an example how technological sovereignty can be achieved through targeted and persistent public support. Though the technology has only recently achieved market maturity, technology development reaches back over 30 years. The origins can be traced back to the launch of the EUREKA initiative in 1985, aimed at bridging "the widening technological gap between Europe and its global competitors: notably the USA and Japan" (EUREKA, 2005, p. 11). EUREKA is an on-going bottom-up initiative to support joint trans-national R&D projects of companies, universities, and research institutions. Projects are (usually) initiated and led by industry, and supported by a varying group of EUREKA member states. One of the earliest collaborations under the umbrella of EUREKA was JESSI (Joint European Submicron Silicon Initiative), a joint initiative of 13 countries launched in 1989 "with the goal of regaining ground lost to Asia and the USA in microchips" (EUREKA, 2005, p. 15). This included, *inter alia*, technology development for European equipment manufacturers. Work started in 1990 and continued until 1996. Afterwards, it was continued in the EUREKA *clusters*[16] MEDEA (Microelectronics Development for European Applications, 1997–2000), MEDEA+ (2001–2008), and CATRENE (Cluster for Applications and Technology Research in Europe on Nano-Electronics, 2008–2015).

The first projects dealing specifically with EUV lithography (but building on previous results) were EXTATIC, EUV Sources, and ExCITE, conducted under the umbrella of the MEDEA+ cluster between 2001 and 2005.[17] Each of these projects involved either ASML, or Zeiss, or both as project partners. Work was continued, amongst others, in the MEDEA+ project EAGLE (2006–2008) as well as the CATRENE project EXEPT (2009–2012, see CATRENE, 2019). With the start of the Seventh Framework Programme for Research, Technological Development and Demonstration (FP7, 2007–2013), the EU introduced *Joint Technology Initiatives (JTIs)* (or *Joint Undertakings*) as a new funding instrument. These long-term Public-Private Partnerships based on Article 187 of the Treaty on the Functioning of the EU "combine private sector investment and national and European public funding", and grant funding based on open calls that are in turn derived from a Strategic Research Agenda.[18] JTIs were introduced to further the cooperation

[16]EUREKA clusters are longer-term strategic initiatives in which the collaborating partners agree on a multi-year roadmap to define strategic domains and aims, develop a programme of projects to achieve those aims, and initiate regular calls (EUREKA, 2005, p. 38).

[17]See `www.catrene.org` for project information on both the MEDEA+ and the CATRENE cluster.

[18]See Council Decision 2006/971/EC of 19 December 2006 concerning the Specific Programme 'Cooperation' implementing the Seventh Framework Programme of the European Community for research, technological development and demonstration activities (2007-2013) (OJ L 400/111f.).

between the Framework Programme and EUREKA (see e.g. EUREKA, 2006, CATRENE, 2019). Funding of EUV lithography was henceforth continued in the JTIs ENIAC (2008–2013), especially in the projects E450EDL and E450LMDAP), and ECSEL (since 2014, especially the projects SeNaTe, TAKE5, TAKEMI5, TAKES3).[19] Each of the mentioned projects involved ASML and Zeiss, and further partners from academia and industry, in Germany and other European states. Overall, the German government has invested nearly 100 million euros into the development of the EUV lithography since 1998. Today, funding for microelectronics in general, and chip lithography in particular is continued within the new German Federal Government's Framework Programme for Research and Innovation 2021–2024, "Microelectronics. Trustworthy and sustainable. For Germany and Europe." (BMBF, 2021b), the on-going European JTI ECSEL and the EUREKA cluster PENTA, and the IPCEI (Important Project of Common European Interest) on Microelectronics (`www.ipcei-me.eu`).

EUV lithography is a good example for the added value and success of European industry-focused R&D funding initiatives like EUREKA with regard to technological sovereignty. As shown by Benfratello and Sembenelli (2002) and Bayona-Sáez and García-Marco (2010), participation in EUREKA has a positive impact on the performance of participating firms in general. One determinant of this success is the establishment of collaborative links between the participating firms and research institutions (see Peterson, 1993, Benfratello and Sembenelli, 2002). Indeed, the cooperation and co-creation of the important stakeholders in the innovation chain has been a crucial success factor for the development of EUV lithography, and ASML has deliberately exploited this in other ways as well, e.g. through a customer co-investment programme (see Banerjee and Sharma, 2015).

6 Conclusion

Technological sovereignty has advanced into the political debate since 2019, and we predict that it is likely to stay as an issue for policy makers, and a target of policy initiatives. Debates surrounding its meaning and its practical implications are thus likely to continue, including the pessimistic variants which equate technological sovereignty with a strive towards de-globalization.

In contrast, we have derived a definition of technological sovereignty which is based on competences (or abilities) and ambitions of a polity. This definition has enabled us (i) to relate technological sovereignty to notions of political and economic sovereignty, (ii) to show that research, education, and innovation policy lie at the heart of strengthening technological sovereignty, and (iii) to reason that technological sovereignty and interna-

[19] See https://cordis.europa.eu for project descriptions.

tional cooperation are not antagonisms, but in fact mutually dependent. Ultimately, we argue in favor of technological sovereignty through international cooperation.

We have also argued that technological sovereignty requires a holistic innovation policy, ranging from the public support of research, research transfer, and the qualification of scientists and professionals to initiatives on standardization and setting the right regulatory framework. A *sovereignty-oriented innovation policy* shares this aspect with mission-oriented policies. We would like to emphasize, however, that there are clear differences between the two approaches. Maintaining and strengthening technological sovereignty is an enduring task, not the pursuit of a well-defined goal, to be achieved at some point and abandoned afterwards. The technology pipeline must be filled continuously. Applications of new technologies often materialize with a substantial delay. Our case studies, as well as the mRNA technology whose initial focus was on cancer treatment and which has now resulted in the first vaccine against Covid-19 developed in the Western hemisphere, speak to this. Therefore, the focus on technological sovereignty should be seen as a distinct frame for innovation policy, complementary to the mission-oriented approach.

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