Title of chapter: Technology Policy and Governance

Author names: Jakob Edler; Florian Wittmann

Keywords: technology policy, governance, transformation, technology assessment

Author ORCID i.d. numbers: 0000-0003-0938-1244, 0000-0002-9890-6091

1. Introduction <a>

Governments have always had a specific interest in the issue of technological development (Braun 1997; Ergas 1987, p. 191; Lundvall and Borrás 2005; Mowery 1995, p. 513). Already for ancient regimes like Greek democracies or the Roman Empire, one prime and permanent concern of the ruling class was expanding military strength and safeguarding the security of their citizens through the development and application of advanced technologies. Over the centuries, and against the background of industrialization and the emergence of modern nation states, the core functions of the state expanded severely and therefore technology policy was linked to a variety of areas like transportation, telecommunication, health or agriculture.

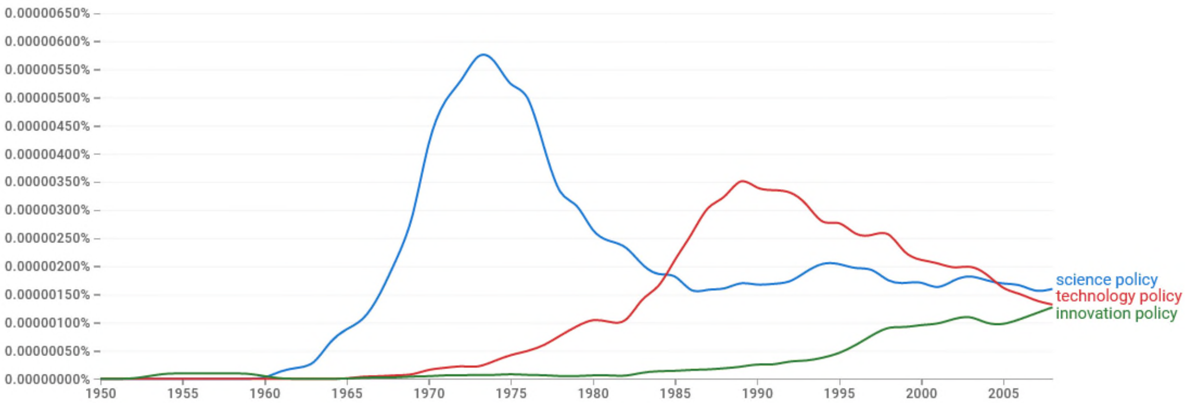
In a very stylised and simplified way, this persistent and enlarging role of technology policy can be explained through three major rationales. First, most importantly, it has to do with the idea that genuine tasks of the state, like defence, security, health provision, etc. can be performed more effectively and efficiently with the use of new technology. Second, new technologies promise to improve the way citizens, firms and the public sector satisfy their own needs and pursue their own goals. Finally new technologies are seen as critical for the competitiveness of companies and the productivity of economies, which in turn is a key determinant for the long term welfare of citizens.

Given this ubiquitous expectations associated with "new" technologies, the state has always supported the development and deployment of technologies. In consequence, one cannot understand the development of technology without understanding governmental policy. The direction technological development takes, the choice of knowledge creation underpinning technological development, the purposes for which technologies are supported and the expectation of impact of new technologies is inevitably influenced by and linked to governmental policy. Therefore, understanding governmental expectation management, support instruments and regulatory framework conditions is a prerequisite for engaging in holistic technology assessment.

We understand technology policy as public action that supports the development and deployment of specific, selected technologies based on different rationales and purposes. It is thus located at the intersection of numerous other policies like defense, science, innovation, economic, industrial, and more recently transformative policies. Particularly with science and innovation policy - boundaries have been fluent, as for most technologies scientific knowledge is critical input, and once technologies are introduced into broader use they turn into innovation. Therefore, these policies often are often subsumed under the shared label of science, technology and innovation (STI) policy. What sets technology policy apart from both science and innovation policy by its in-built prioritization of selected technologies and sectors that are considered of key strategic importance, thereby prioritizing directionality over the strengthening of overall framework conditions (Boekholt 2010; Lundvall and Borrás 2005).

Technology policy particularly gained particular importance since the end of the 1960s, eventually becoming more common than science policy. Since the early 1990 the reference to technology policy has somewhat decreased, while in parallel innovation policy gained relevanve (cf. Figure 1). This has to do with shifts in basic rationales, see below. However, we also need to stress that there has been no linear development from science to innovation policy (Lundvall and Borrás 2005), as these policy fields have their own distinct focus (Cunningham and Link 2021) but were interacting and being shaped by different debates, semantic shifts and national cultures (Boekholt 2010) .

Figure 1: Term frequency for science, technology and innovation policy in google



Source: Google ngram viewer, December 2 2022

With this chapter we want to shortly outline the very nature of technology policy as a reference for subsequent chapters in this volume. We defined technology policy and delineated it from other, related policies like science and innovation policy. We will in the following explore the changes in priorities and rationales for technology policies over time, followed by a brief outline of the major instruments and governance arrangements associated with the different rationales for technology policy. To understand those cumulative rationales and its related instrumentation is critical for the understanding of the changing justifications for technology policy which in turn shape the expectations - and worries - as to future technologies. We finally formulate a few propositions as to how the changing nature of technology policy interacts with technology assessment.

2.Changing rationales and priorities of technology policy <a>

The shift in the manifestation of technology policy is underpinned by changing theoretical and ideological rationales over time, providing different arguments for the state to intervene in the development and deployment of technologies in market economies. This shift, as most shifts in policy development, was characterized by an interplay between an epistemic community in economics and, later on, innovation studies, on the one hand, and policy-making on the other hand.

The post-WWII time was characterized by a period of technological optimism finding its expression in Vannevar Bush's influential report (1945) *Science, The Endless Frontier*. Emphasizing the importance of basic research as the source for progress, it implied a linear understanding whereby investment in science would lead to technology and innovation and finally realising public welfare. In the context of the beginning Cold War and systems competition in the 1950s and 1960s technology policy strongly focused on sectors like defense or technology fields that were considered as crucial for national sovereignty and prestige (space/nuclear power) and critical resources (communication and information technology) (Lundvall and Borrás 2005, p. 609). A clear example of priority setting were the mission-oriented approaches (Ergas 1987) of that time like the Apollo mission, aiming to deploy big science to meet big problems (cf. Weinberg 1967).

The theoretical underpinning of the first wave of interventionist policies was the so-called market failure rationale. The economic argument is that uncertainty and external effects of basic research lead to an underinvestment of the market when it comes to generating the basis for new technologies. Technologies are to a large extent based on knowledge that is generated in long-term basic research that is highly uncertain, and so is the rate of private investment. In addition, knowledge generated in basic research is a co-operative endeavour, across organisations and countries. The results of those endeavours can hardly be internalised to individual firms (Arrow 1962; Nelson 1959). The knowledge leakage triggers free rider behaviour by firms. The role of the state therefore is investment in basic research that is available across the innovation system in order to overcome the existing market failure.

While initially economic considerations were not yet dominating, since the late 1960s there was a gradual shift towards linking technological development and economic priorities (OECD 1963;

Steinmüller 2010) which gained increasingly traction in the 1970s and 1980s. The economic stagnation after the oil crisis and the need to modernize existing industrial structures sparked interest in enhancing economic growth and competitiveness through technological progress (Cunningham and Link 2021; Steinmüller 2010, p. 1088). Starting to systematically compare the economic and innovation performance of countries, scholars realised that economies differed a lot in the way they produced and deployed technology (Edler and Fagerberg 2017, pp. 8–9). They recognised that that effective production of knowledge that is supposed to support the economic development is based on capabilities, creativity, and connectivity within innovation systems and a range of framework conditions (regulation, finances, culture of risk taking etc.). In particular the concept of national innovation systems stressed the importance of wider context conditions and of the interplay of a variety of actors, regulation, policy and infrastructures that are largely shaped at a national level (Freeman 1987; Lundvall 1992; Nelson 1993). This concept also took a more holistic view on the generation and deployment of technologies (Metcalfe 1995; Mowery and Rosenberg 1989). As the interest shifted to innovations as novelties that are put to a meaningful use, technologies were reframed as one input or source for innovation, moving the focus away from specific technologies to overall conditions and capabilities through which innovations are generated and deployed.

The result was an increasing fusion of technology, science and industrial policy under the label of innovation policy (Rothwell 1982, p. 3) for national economic competitiveness. With the advent of innovation policy, the meaning of technology policy in a traditional sense was limited to so-called key/generic technologies which were of cross-cutting relevance for different industrial sectors such as Information and Communication Technologies in the 1970s or 1980s (cf. OECD 1980).

This changing understanding based on empirical induction (Dodgson 2017) was accompanied by evolutionary economist theorising, stressing the importance of diversity, mutation and selection mechanisms for the choice of technologies and innovation (Metcalfe 1995). These developments shifted the demands on the state. Instead of overcoming market failure, the state was supposed to mend system failures, i.e. poor capabilities and inter-connectivity and framework conditions.

More recently, innovation and also technology policy have been affected by two major trends that contribute to further convergence of national technology policy styles. First, the emergence of the paradigm of transformative policy-making. Frustrated by the poor ability of science and innovation systems to deliver on solutions for societal problems, to deliver on public value (Bozeman and Sarewitz 2005), two dominant models emerged. The top down model as propagated most vividly by Mazzucato (2013, 2018), in which the state formulates missions and that gained enormous traction among OECD countries (Larrue 2021), and an alternative model, in which state intervention is directed towards accelerating and orchestrating bottom up transformational dynamics (Schot and Steinmueller 2018).

The theoretical rationale occuring in the late 2010s was the recognition of a multiple transformational failure of systems (Weber and Rohracher 2012): directionality failures (no alignment of technological and innovation activity in the direction needed to solve certain problems), demand articulation failure (and thus poor match between innovations developed and readiness to absorb them), policy-coordination failure and reflexivity failure (the lack of methods and concepts to understand the progress made towards transformation of systems). Consequently, to react to those failures and mobilise technology for transformations, the state now has become - again - more interventionist. Thus, directionality is back in, but not within technology-driven missions for the big national (defense) projects as in the 1950s to 1970s, but for selecting technologies and innovations based on defined societal ends (Mowery et al. 2010).

Finally, a more recent additional development is the recognition, triggered through the experience of the Trump presidency, Brexit, the Covid crisis and the fall-out of the Russian war in Ukraine that in times of increasing geo-political uncertainties states cannot take the access to all the technologies they need for granted. The concept of technology sovereignty thus has become a very strong undercurrent of any technology policy globally (Edler et al. 2021).

3. Technology policy in practice: instruments and governance <a>

Each phase of technology policy, with its distinct rationales, had its own mix of policy instruments. When rationales changed, new instruments were added while existing ones remained in place (Edler and Fagerberg 2017). Thus, the variety of instruments that support or influence the generation and deployment of technology has mushroomed in the past decades.

In the first major rationale, the market failure, the state uses institutional funding of research in Universities and public research institutes and grants for research projects for individuals/ teams across organisations to facilitate technological development. The link to technology policy, i.e. the development of technologies is twofold. First, it is indirect and random. Scientists in public Universities and selected public research organisations utilise their institutional funding to perform research in areas of their own choice ("freedom of science"), with little or no directionality, developing new technologies in a bottom up manner. Equally, they take advantage of open funding programmes that do not define specific scientific, but fund on the basis of excellence and / or cooperation (see below). The second link to technology development is direct, relying more on a top down approach: Setting up Non-public-non-University research institutions in specific areas of science and technology to deliver knowledge that is embodied into technologies that are deployed in markets and societies. Moreover, the state moblises research for selected areas and technologies through targeted, directed funding programmes. An example of early times is the Defense Advanced Research Projects Agency (DARPA) issuing calls for research related to technologies being relevant for the military.

In the system failure rationale of technology policy, it is the ambition of policy to support the capabilities and connectivity in the system as a prerequisite for technological progress. Thus, instruments to build up capabilities, enhance the readiness and ability of firms and research organisations to interconnect came into the focus of policy. The instruments deployed under this rationale stretched further, including support of networks and clusters, of incubation and entrepreneurship, and, in particular, all sorts of diverse large scale cooperation programmes as well as capability and awareness measures. Again, similar to the market failure approach, those instruments are both deployed in a bottom up, open fashion, to strengthen the system as such, and in a top down manner, supporting cooperation and capabilities in particular sectors or around specific technologies (Edler, Gök et al. 2016; Edler, Shapira et al. 2016).

In the third rationale, technology policy as part of transformational policies, with a much more interventionist, directional state, an even broader range of instruments are now mobilised that help to overcome the four transformational failures outlined above and deliver on missions and transformations. Most importantly, the design rationale for policy changes, shifting the focus from selecting technologies towards the kind of transformation it should address. This requires new forms of strategic intelligence of the state and a more participatory, mobilising and orchestrating role of the state (Borrás and Edler 2020). This also means that market creation and the actual deployment of a technology is much more in the focus of policy, which implies a better integration of technology with other types of sectoral policies. Further, instruments that support the demand for technologies are becoming more prominent in the policy debate, i.e. public procurement, demand subsidies, training and awareness measures, and regulation.

Due to increasing global uncertainties and the turn towards technology sovereignty, new responsibilities for the state were added, namely to safeguard availability of technological capabilities in areas that are defined as critical for the country (Edler et al. 2021). This once again enlarged the instrumentation. Technology policy is now increasingly part of trade and industrial policy. In a revivial of interventionist industrial policy of the 1970s, subsidies to build up technological capacities and to build up and attract investment for the production of technologies are enhanced. Current examples of interventionist subsidy programmes as technological industrial policy include the "Important Projects of Common European Interest" (IPCEI) in the European Union being framed by arguments of sovereignty (cf. Bora 2023) or the US Inflation Reduction Act.

The way technology policy is implemented and managed by ministries differs between countries (Lundvall and Borrás 2005; Mowery 1995; Rothwell and Dodgson 1992). Besides changing rationales, this is shaped by country specific-perceptions of the economic (and military) position, basic constitutional and broader institutional structures in the different varieties of capitalism, and established traditions of economic policy. In this context Ergas (1987) distinguished between countries pursing a mission-oriented approach based on selected key technologies (USA, France) and countries relying on a diffusion-oriented approach that lacks centralized priority setting and encompasses a broader range of technologies (Germany, Sweden). Further variation may be with regard to internal competition, with policies differing whether they relied in promoting national champions (France) or rather aimed at facilitating internal competition between different enterprises (Lundvall and Borrás 2005).

Related to the different approaches to technology policy, also ministerial responsibility differed considerably across countries, also evolving along paradigms. This includes the creation of dedicated technology ministries (United Kingdom, 1965-1971), the fusion of science and technology ministries (Germany, 1972-1994), the dispersion of technology policy across different ministries (USA), or the embedding into industrial policy, such as the Japanese Ministry of Industry and Trade (Braun 1997; Lundvall and Borrás 2005). While the integration of technology policy into innovation policy has lead to an increasing involvement of different ministries in policy-making (Edler and Fagerberg 2017, p. 14), the shift towards transformative policy-making in some countries has reversed this development, aiming to bundle (parts of) competencies in technology policy with sectoral policies within a single ministry to overcome potential coordination problems across different ministries (cf. e.g. the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology).

Finally, the various rationales and approaches are also related to different ways and scope of interaction of the state with stakeholders. From a narrow focus on the scientific community in the early years of science policy, the scope broadened to encompass all actors relevant within the innovation system, mainly Universities, non University research organisations, firms and intermediaries. Finally, with technology being part of broader transformational policy, the stakeholders broaden further, in fact encompassing all those actor groups that are included or affected by the transformation.

4 Concluding reflections on TA and technology policy development <a>

We finish this short chapter on the history and development of technology policy with a few selective observations as to how the changes of the role of technology policy and its underlying rationales over time co-defined expectations of stakeholders and the public at large and how they have interacted with expectations towards technology assessment (other contributions in this book will have a much more detailed account of developments in TA, cf. Chapter 1, 6).

A first observation is that the expectation towards technology expressed by shifting state policy and stated rationales influence the very need for technology assessment. For example, the immediate period after WW II and the emerging Cold War were characterized by a period of scientific and technological optimism (Grunwald 2019, p. 39; Lundvall and Borrás 2005, p. 605). In combination with the fact that technological development was a key domain of competition between capitalist and socialist systems (e.g. space) and a key pillar of the dominant growth model, potential effects of technology were widely exempt from the debate (Bogner 2021, p. 45).

With techno-optimism of earlier times slowly fading away, the use of technologies was increasingly seen in the context of potential non-intended/undesired side-effects and the need to enhance control over technology development (Bogner 2021, 44f; cf. also Grunwald 2019; Lundvall and Borrás 2005, p. 609).

On the one hand, reactions to changing attitudes at that time were embedded in a general strong sense of state planning optimism in the late 1960s and during much of the 1970s. The idea developed that through systematic state action the direction of progress, and within it the role of technology, can be shaped (Bogner 2021, pp. 45–47). In this rationale, any assessment of technology is framed against the promise it holds to support the stated planning objectives. This was underpinned by a cybernetic understanding of planning in which the state and other actors are able to understand and steer entire technological systems. Rather than giving in to techno-determinism (Ellul 1964 [1954]), this was underpinned by an almost cybernetic understanding of planning in which the state and other actors are able to understand and steer entire (technological) systems into desired directions.

On the other hand, more critical attitudes towards the effects of technologies took hold as well. Key topics sparking considerable societal bottom-up mobilization included nuclear power and its disposal or genetic engineering, requesting increased technological regulation. While societal perspectives on technology were increasingly shaped by a discourse about risk and technic skepticism (Beck 1992; Jonas 1984), technology policy became increasingly a vehicle for promoting economic growth and competitiveness. Against the background of these developments, the backlash of attempts to increase control over technological development were discussions about the potentially hampering effects of regulations on new technologies such as genetic engineering and technology assessment in general (that was sometimes decried as "technology arrestment") on economic competitiveness (Heyen et al. in press).

Despite their considerable conceptual and normative differences, the market failure and system failure rationale had similar implications for TA. Whenever in both rationales institutional and programmatic funding was directed towards specific sectors, science areas and/or technologies, the responsibility of the pro-active state for the potential positive and negative effects to technologies came into focus.

The development of technology policy towards a more transformative approach and higher directionality has also multiple implications for technology assessment. First of all, it requires technology assessment to shift the focus from individual technologies towards a broader systemic perspective taking into consideration different technologies and their interplay (cf. Heyen et al. in press). The consequence for TA here are immense. The expected concrete societal impact of technologies and their interplay -delivering specific solutions - is in the centre of support from the very beginning, affecting the focus on how to facilitate the necessary changes. In principle and as a consequence, core questions of TA have now to be built into the policy design, monitoring and re-design process. At the same time, the in-built directionality of these change processes may expose TA to the challenge how to deal with un-intended/undesirable effects of such transformation processes and how to weigh them against the overarching societal challenges that these policies aim to address.

Finally, and unrelated to the specific policy approach taken, there is a general challenge related both to technology policy as well as to technology assessment, i.e. the fact that increasingly critical and contested technologies are developed in corporate labs and deployed very quickly through the marketplace. While firms always have been major drivers of innovation, the immense capital in the hands of a limited number of global companies in the digitalised economy takes much of the control out of the hands of the state. States increasingly are behind the curve when it comes to supporting future disruptive technologies and struggle to keep up with critical developments critical for citizens and companies alike - ChatGPT being just one of many examples. Technology Assessment in those constellation, without meaningful role of the state in the generation and deployment of a technology, is in danger of being too late or not finding the right addressee early enough.

These few observations point towards a complex relationship between technology policy and technology assessment which appears to have changed considerably over time. Technology policy, its rationale and instrumentation, are embedded in basic rationales as to the role of the state in the economy and as to why and how the state may intervene in technological developments and deployments. These rationales themselves interact with broader ideas as to the very ability of societies to shape the process of technological development and the very drivers - optimistic or pessimistic ones - to do so. One may hope that the link of technology policy into transformational policy approaches brings the concerns of Technology Assessment right into the discourse very prominently and early in the policy process. However, the speed with which technological decisions are being taken in the context of transformative policies and global turbulences with systems competition and fears of loss of sovereignty may - ironically - reduce the role of TA just when we need it most.

References

Arrow, K. (1962), ‘Economic Welfare and the Allocation of Resources for Innovation’, in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity,* Princeton: Princeton University Press, pp. 609–25.

Beck, U. (1992), *Risk Society: Towards a New Modernity*: SAGE.

Boekholt, P. (2010), ‘The Evolution of Innovation Paradigms and their Influence on Research, Technological Development and Innovation Policy Instruments’, in R.E. Smits, S. Kuhlmann and P. Shapira (eds), *The theory and practice of innovation policy: An international research handbook,* Cheltenham: Elgar, pp. 333–59.

Bogner, A. (2021), ‘Politisierung, Demokratisierung, Pragmatisierung. Paradigmen der Technikfolgenabschätzungi im Wandel der Zeit’, in S. Böschen, A. Grunwald, B.-J. Krings and C. Rösch (eds), *Technikfolgenabschätzung: Handbuch für Wissenschaft und Praxis,* Baden-Baden: Nomos, pp. 43–58.

Bora, S.I. (2023), ‘‘A Sovereign Europe’? Strategic Use of Discourse at the Service of French Economic Interests in EU Politics (2017–2022)’, *Journal of Common Market Studies*(online first).

Borrás, S. and J. Edler (2020), ‘The roles of the state in the governance of socio-technical systems’ transformation’, *Research Policy,* **49**(5).

Bozeman, B. and D. Sarewitz (2005), ‘Public values and public failure in US science policy’, *Science and Public Policy,* **32**(2), 119–36.

Braun, D. (1997), *Die politische Steuerung der Wissenschaft: Ein Beitrag zum 'kooperativen Staat'*, Frankfurt/New York: Campus Verlag.

Bush, V. (1945), *Science: The Endless Frontier*, Washington, DC: United States Government Printing Office.

Cunningham, J. and A.N. Link (2021), *Technology and innovation policy: An international perspective*, Cheltenham, UK, Northampton, USA: Edward Elgar Publishing.

Dodgson, M. (2017), ‘Innovation in firms’, *Oxford Review of Economic Policy,* **33**(1), 85–100.

Edler, J., K. Blind, H. Kroll and T. Schubert (2021), ‘Technology Sovereignty as an Emerging Frame for Innovation Policy – Defining Rationales, Ends and Means’, Karlsruhe.

Edler, J. and J. Fagerberg (2017), ‘Innovation policy: what, why, and how’, *Oxford Review of Economic Policy,* **33**(1), 2–23.

Edler, J., A. Gök, P. Cunningham and P. Shapira (2016), ‘Introduction: Making Sense of Innovation Policy’, in J. Edler, P. Cunningham, A. Gök and P. Shapira (eds), *Handbook of innovation policy impact,* Cheltenham, UK, Northampton, MA, USA: Edward Elgar Publishing, pp. 1–17.

Edler, J., P. Shapira, P. Cunningham and A. Gök (2016), ‘Conclusions: Evidence on the effectiveness of innovation policy intervention’, in J. Edler, P. Cunningham, A. Gök and P. Shapira (eds), *Handbook of innovation policy impact,* Cheltenham, UK, Northampton, MA, USA: Edward Elgar Publishing, pp. 543–64.

Ellul, J. (1964 [1954]), *The technological society*, New York: Knopf.

Ergas, H. (1987), ‘The importance of technology policy’, in B.R. Guile and H. Brooks (eds), *Technology and Global Industry: Companies and nations in the world economy,* Washington, DC: National Academies Press:, pp. 191–245.

Freeman, C. (1987), *Technology Policy and economic performance: Lessons from Japan*, London: Pinter.

Grunwald, A. (2019), *Technology Assessment in Practice and Theory*, Milton: Routledge.

Heyen, N., M. Friedewald, E. Jochem, T. Reiß and A. Thielmann (in press), 'Assessing technological innovations: From early warning to the governance of socio-technical transformations.', in J. Edler and R. Walz (eds), *Innovation and sustainability research in transition. Research questions and trends over the last 50 years,* Heidelberg: Springer.

Jonas, H. (1984), *The imperative of responsibility: In search of an ethics for the technological age*: University of Chicago press.

Larrue, P. (2021), 'The design and implementation of mission-oriented innovation policies: A new systemic policy approach to address societal challenges', OECD, Paris.

Lundvall, B.-A. (1992), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London: Pinter Publishers.

Lundvall, B.-A. and S. Borrás (2005), 'Science, Technology, and Innovation Policy', in J. Fagerberg, D.C. Mowery and R.R. Nelson (eds), *The Oxford Handbook of Innovation:* Oxford University Press, pp. 599–631.

Mazzucato, M. (2013), *The entrepreneurial state: Debunking public vs. private sector myths*, London: Anthem Press.

Mazzucato, M. (2018), *Mission-Oriented Research & Innovation in the European Union: A problem-solving approach to fuel innovation-led growth*: Publications Office.

Metcalfe, J.S. (1995), 'Technology systems and technology policy in an evolutionary framework', *Cambridge Journal of Economics,* **19**(1), 25–46.

Mowery, D.C. (1995), 'The practice of Technology Policy', in P. Stoneman (ed.), *Handbook of the economics of innovation and technological change,* Oxford: Blackwell, pp. 513–57.

Mowery, D.C., R.R. Nelson and B.R. Martin (2010), 'Technology policy and global warming: Why new policy models are needed (or why putting new wine in old bottles won't work)', *Research Policy,* **39**(8), 1011–23.

Mowery, D.C. and N. Rosenberg (1989), *Technology and the Pursuit of Economic Growth*, Cambridge, New York, Port Chester: Cambridge University Press.

Nelson, R.R. (1959), 'The Simple Economics of Basic Scientific Research', *Journal of Political Economy,* **67**(3), 297–306.

Nelson, R.R. (ed.) (1993), *National innovation systems: A comparative analysis*, Oxford: Oxford University Press.

OECD (1963), 'Science, Economic Growth and Government Policy', OECD, Paris.

OECD (1980), *Technical change and economic policy: Science and technology in the new economic and social context*, Paris: OECD.

Rothwell, R. (1982), 'Government innovation policy', *Technological Forecasting and Social Change,* **22**(1), 3–30.

Rothwell, R. and M. Dodgson (1992), 'European technology policy evolution: convergence towards SMEs and regional technology transfer', *Technovation,* **12**(4), 223–38.

Schot, J. and W.E. Steinmueller (2018), 'Three frames for innovation policy: R&D, systems of innovation and transformative change', *Research Policy,* **47**(9), 1554–67.

Steinmüller, W.E. (2010), ‘Economics of Technology Policy’, in Hall, Bronwyn H., Rosenberg, Nathan (ed.), *Handbook of the economics of innovation,* Amsterdam: North-Holland, pp. 1181–1218.

Weber, K.M. and H. Rohracher (2012), ‘Legitimizing research, technology and innovation policies for transformative change’, *Research Policy*, **41**(6), 1037–47.

Weinberg, A.M. (1967), *Reflections on Big Science*, Cambridge, MA: The MIT Press.