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The Roles of the State in the Governance of Socio-Technical Systems' Transformation

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Abstract

The transformative turn of innovation policy has resulted in calls for a more entrepreneurial and directional role of the state. However, the multiple roles that the state might play remains underexplored. This paper studies the embedded role of the state in four distinct modes of governance of socio-technical systems. Using a three-pillar analytical model, the paper examines four illustrative cases: cryptocurrencies, smart cities, automated vehicles, and nuclear power. The paper identifies 13 different roles of the state: observer, warner, mitigator, opportunist, facilitator, lead-user, enabler of societal engagement, gatekeeper, promoter, moderator, initiator, guarantor and watchdog. The conceptualization of these roles serves to understand that the transformative agency of the state is leveraged/constrained by the modes of governance, and that it is also ultimately exercised through specific mixes of roles.

Keywords: transformative, innovation policy, transitions, diffusion, grand challenges, governance

JEL: O330 , O380, O310

Highlights:

- The role of the state in the transformation of socio-technical systems remains underexplored.
- We examine 4 illustrative cases: cryptocurrencies, smart cities, automated vehicles, nuclear power.
- We identify 13 different roles of the state: observer, warner, mitigator, opportunist, facilitator, lead-user, enabler of societal engagement, gatekeeper, promoter, moderator, initiator, guarantor and watchdog.
- The transformative agency of the state is exercised through mixes of roles
- These are leveraged/constrained by the modes of governance where state action is embedded

1. Introduction

Increasingly the purpose of innovation policy is to address specific problems. Hence, it is widely recognized that innovation policy has to give direction and has to support not only the generation of innovations, but also their diffusion and use. This has led to claims that innovation policy has to play its part for system transformation towards a more societally desirable outcome, and therefore policy has to be "transformative" (Weber and Rohracher, 2012) (Kuhlmann and Rip, 2018) (Schot and Steinmueller, 2018) (Foray, et al., 2012). This demand on the state to develop transformative policies is normatively reasonable. However, it needs to be based on a theoretical and empirically informed understanding about the different roles of the state. This nuanced view is needed in order to avoid unrealistic aspirations or simplified views about what can the state (and thus public policy) do in the complex governance processes of socio-technical change. Hence, the role of the state needs to be considered in the context of governance, and needs as well to be studied from the understanding that it is not a unitary actor.

The literature has long discussed that the way innovations are developed and used is related to societal and economic dynamics, as well as institutional frameworks and political choices (Sovacool and Hess, 2017). Institutional economic approaches propose an institutional analysis of modern capitalist economies and innovation systems from the understanding that institutional arrangements are complementary to each other (Amable, 2000), that these vary across varieties of capitalism (Hall and Soskice, 2001), and that they have effects on innovation processes (Taylor, 2004). Evolutionary economy approaches share this institutional approach, but put emphasis on co-evolution processes of diversity and selection (Nelson and Winter, 1982), which are fundamental for innovation policy-making (Metcalfe, 1995).

Yet, there is abundant historical evidence that science and technology based innovations (disruptive or not) often have not managed to become part of social life, even when there was an expectation that they might address important social challenges (Konrad and Alvial Palavicino, 2017). Hence, the calls for problem-oriented or transformative research and innovation policies have originated from the frustration of insufficient or slow transformation, as problems like climate change, or antibiotic resistance, continue to plague our societies. The basic premise of these calls is that a conscious public policy can influence directionality of innovation and, more importantly, change the socio-technical systems. While the limits of policy-making are conceded, there is nevertheless a new general optimism about the entrepreneurial state creating new markets (Link and Link, 2009) (Mazzucato, 2016). This laudable optimism, however, threatens to undermine the very purpose it is addressing if it is not underpinned by a sound understanding of the different roles of the state in different governance modes of socio-technical systems. Therefore, we need to activate the existing literature about the governance of socio-technical systems, understood as the interplay of the different ways in which agents intentionally and deliberately interact reflexively in order to influence, promote or inhibit transformative processes. Only if this is taken into consideration can we better approach the research question about which embedded role(s) the state[1] takes in the governance processes of socio-technical systems' transformation.

[1] This paper understands 'state' as governmental action, here including the notions of 'government' and 'public policy' as defined in the literature (see section 2).

The literature on the governance of socio-technical change offers useful insights into the complexity of these governance processes. Usually it is related to issues about the integration of social concerns associated to the inherent uncertainties of innovation (Fisher, 2019) (Stilgoe, et al., 2013) (Irwin, 2006) (Lindner, et al., 2016). When dealing with emerging science and technology, it is important to note that modes of tentative governance tend to co-evolve with definitive (established) governance modes (Kuhlmann, et al., 2019). Thus, tentative governance captures conceptually the current observable phenomenon of creating open spaces for learning and for cautious experimentation in view of trying new approaches of co-ordination (Budde and Konrad, 2019) (Rip, 2018). The combination of tentative and definitive governance modes might not always be unproblematic particularly in terms of maintaining synergies between public and private actors (Hopkins, et al., 2019) (Lyall and Tait, 2019). What is clear from the vast literature, however, is that in the majority of cases, both in tentative and in established governance processes, the state plays a distinct role that is not spelled out conceptually.

Despite all their richness and valuable insights, the institutional and evolutionary economic literature still fails to capture conceptually the various roles of the state, beyond the overall two roles of creating/correcting markets. Likewise, the governance of innovation literature fails to embed properly state action in processes of socio-technical system transformation. As the state is called back in, this gap limits our ability to understand the different roles of the state in the transformation of socio-technical systems, which we understand as a change towards an expected improvement in the nature and functionality of the socio-technical systems, addressing pressing grand challenges.

This article aims at filling this gap by addressing and conceptualising the fundamental diversity of the roles of the state vis-a-vis the bold demands that the state shall deliver transformation. It does so by taking existing governance studies as a starting point, and by building further on them by focusing on the diversity of the roles of the state in different governance contexts. Thus, the paper proceeds as follows. The next section reviews succinctly the literature devoted specifically to the role of the state, in view of emphasizing the embeddedness of the state in the governance of socio-technical systems. The subsequent section offers a framework on four ideal models of governance of socio-technical systems based on our previous work (Borrás and Edler, 2014). Section 4 examines four illustrative cases of socio-technical system changes associated with the four modes of governance (cryptocurrencies, smart cities, automated vehicles, and nuclear energy). In analysing the interaction of three analytical pillars (the capability of agents, the instruments to influence change, and the social acceptance) (see section 3) these four cases serve to identify and characterise the different roles of the state. Hence, our four cases are a pre-study (Swedberg, 2012), that is, an analysis based on consistent insights from empirical observations that serve to conceptualise (and eventually theorise) about a phenomenon that remains understudied (the various roles of the state).

Thereafter, section 5 defines and conceptualises 13 different roles, discussing the findings. The last section of the paper considers the usefulness of our conceptual aproach, acknowledges some limitations, and suggests some venues for future research agenda such as studying variation within each mode of governance, as well as different forms of transformation/non-transformation.

2. The role of the state as contextualized, complex and dynamic governmental action

The role of the state in technological development and innovation processes has been a recursive topic since the 1950s following two main approaches, namely, one that sees the state as correcting market and system failures that limit the development and deployment of knowledge, technology and innovation (Martin and Scott, 2000); and another approach that sees the role of the state as creating markets and directly engaging in concrete missions to solve societal problems (Edler and Fagerberg, 2017). Whereas the former sees the role of the state mainly reacting or specific system deficiencies or 'fixing' negative externalities, the later sees the role of the state mainly in proactive terms ahead of developments and unfolding particular visions of socio-economic progress (Mazzucato, 2016). In fact, it would be possible to re-read the last decades of academic discussions about the rationales of innovation policy under these two fundamental approaches (Fagerberg, 2017), focusing on different areas of policy intervention (Edler, et al., 2016) (Borrás and Edquist, 2019).

In more recent years, however, the debate about the role of the state has gained again scholarly attention for two reasons. One reason is because scholars have demonstrated that in spite of normative views against state intervention to influence the direction of technological change, historical evidence shows very clearly an active state engagement, particularly in specific areas like defence, health or space. This is the case in the USA, where several authors have made efforts to show empirically the entrepreneurial spirit of USA state intervention with purposeful intent and with willingness to assume risks. For example, the "Advanced Technology Program" (Link and Link, 2009), the state-promoted inventions leading to Apple's i-Pad (Mazzucato, 2014) or the Small Business Innovation Research (SBIR) program (Leyden and Link, 2015). The second reason why the role of the state has gained attention during the past years has to do with the emergence of a new political agenda around the so-called grand social challenges. The definition of the Millenium development goals by the United Nations in 2000 (thereafter Sustainable Development Goals in 2015) has successfully put those challenges at the forefront of the political agenda of many governments and of a wide array of civil society organizations and companies around the world. This broad political agenda has naturally reached innovation policy, with policy reports reflecting on that (Aho, et al., 2006) (Boon and Edler, 2018), as well as a growing scholarly attention on the relation of research and innovation policy to processes of socio-technical systems' change (Kern, 2012) (Edmondson, et al., 2018).

In spite of the recent recognition of the (new) activism of the state, the essential dichotomy of "state *correcting* market or system failures or state *creating* market or social solutions" seems to prevail in much of the literature. Beyond this dichotomy, however, there seems to be an analytical 'blind spot' about the concrete role(s) of the state which tends to underestimate the embedded nature of state action. State action is highly embedded because it operates within broader forms of collective action, the so-called 'governance', which is the ability of a society to develop and implement collective choices (Pierre and Peters, 2001). This means that state action operates in a societal and socio-technical context, developing many different forms of collaboration and interaction with social actors, and that the state is not always on the driving seat.

As mentioned earlier, this article understands 'state' as governmental action including the notions of 'government' and 'public policy'. In the literature, 'government' is defined in two general meanings. One that sees government as collective action through the exercise of legislative, executive or judicial power; and another that refers specifically to government solely as the executive power, comprising the (democratically elected) politicians and the administrative branch of the executive (public administration at different levels). Likewise, 'public policy' is generally defined as the concrete actions and initiatives that give concrete 'life' to the general statements/decisions of the government. Our definition of 'state' includes 'government' and 'public policy', encompassing different levels and forms of governmental action.

3. Analytical framework and case selection

It is important to note that this paper is a conceptualization effort in the form of a pre-study (Swedberg, 2012). That is, the gathering of consistent insights to support conceptualizing an understudied phenomenon. Hence, we aim at conceptualizing the various roles of the state in relation to four ideal-types of modes of governance of socio-technical systems' transformation. Therefore, we proceed in two steps. The first step (building from our previous work) is the ideal-type typology of governance of socio-technical systems transformation, which "explicates the meaning of a concept [governance of socio-technical systems] by mapping out its dimensions" (Collier, et al., 2012) . p 218. The Weberian approach of ideal-types, offers an interpretative understanding of social action (Aronovitch, 2012), in our paper, the transformation of socio-technical systems.

In the second step (the novelty of this paper), we undertake the interpretative work of identifying different roles of the state within each of these four modes. In order to do so, we use four illustrative cases (one for each of the four ideal-types of modes of governance). The work of identifying the specific roles has been done by examining 3 analytical questions, which serve as the basis for careful considerations of what characterizes specific forms of state action.

We propose our own definition of socio-technical systems as "articulated ensembles of social and technical elements which interact with each other in distinct ways, are distinguishable from their environment, have developed specific forms of collective knowledge production, knowledge utilization and innovation, and which are oriented towards specific purposes in society and economy" (Borrás and Edler, 2014) p.11. The notion of governance allows two important differentiations. First, the driver of change of socio-technical systems might be state or non-state actors. Second, the mode of governance might differ in terms of the type and distribution of organizational dominance, ranging from heterarchical process with no obvious dominating centre, to hierarchical top down processes that are dominated by a limited group of actors. Following that we suggest a four-fold typology of governance modes: self-regulation, primus inter pares, oligopoly and command and control (table 1).

Having defined the four-fold typology of modes of governance, the second step aims at conceptualizing different roles of the state. Our analytical framework proposes to examine three specific analytical pillars, each framed around a research question: (1) how are the capabilities of agents to contribute to and influence change distributed in the system, and how do they interact with the opportunity structures which are resulting from the co-evolution of new technologies with institutional framework conditions in situations of change?, (2) what are the instruments used by agents to influence change; and (3) what is the degree of social acceptance of the outcomes and processes of change, and what are the forms of social contestation? (Borrás and Edler, 2014).

In order to undertake this second step, we select four illustrative cases. The selection of cases was based on extensive scanning of on-going system transformations and was guided by the need to identify, based on this ex ante information, one case for each mode: cryptocurrencies (illustrating 'self-regulation'), smart cities (illustrating 'primus inter pares'), automated vehicles (illustrating 'oligopoly'), and nuclear power (illustrating 'command and control'). Table 1 locates them.

Table 1: Illustrative cases of the four modes of governance

	Driven by state actors	Driven by non-state actors
Hierarchial, dominated	Nuclear power *(Command and control)*	Automated vehicles *(Oligopoly)*
Heterarchical, non-dominated	Smart Cities *(Primus inter Pares)*	Cryptocurrencies *(Self-regulation)*

Elaborated from: (Borrás and Edler, 2014)

The case descriptions are based on a combination of literature reviews and secondary data sources. Scholarly literature on the four cases was selected based on their relevance, credibility and quality. Furthermore, fourteen experts in the corresponding field areas have provided valuable inputs identify missing aspects, qualifying our analysis of the elements, and verifying our findings[2]. The authors of this paper remain the sole responsible for the case descriptions and their interpretation.

4. The four illustrative cases

4.1 Self-Regulation: Crypto Currencies

The first case is about cryptocurrencies, developed and diffused using blockchain technology - a technology that provides a secured end-to-end information chain. Cryptographic algorithms create verifiable authenticity and immutability of digital documents, allowing an automatic verification of transactions by the nodes in a chain. The technology is potentially disruptive because it removes the need of the trusted third party in complex transactions, making them cheaper, automated, and traceable. In the field of currencies, blockchain has provided payment forms that are alternative to conventional currencies. There are currently around 1600 cryptocurrencies[3], most of them created after 2012. The well-known Bitcoin remains the largest with an approximate market capitalization of 104b USD[4]. There are two types of cryptocurrencies: coins (operating their own blockchain) and tokens (using an existing open blockchain platform). Cryptocurrencies are an exemplary case of a self-regulation mode of governance. The complex social technical system of cryptocurrencies has

[2] We are thankful to the following experts' inputs: Nuclear energy: Wolfgang Eichhammer, Fraunhofer ISI, Germany; Andrew Stirling, SPRU, University of Sussex, UK; Mario Ragwitz, Fraunhofer ISI, Germany; and Hideaki Shiroyama, Tokyo University, Japan. Automated vehicles: Azra Habibovic, RISE Viktoria, Sweden; Elisabeth Dütschke, Fraunhofer ISI, Germany; Michael Krail, Fraunhofer ISI, Germany; Cryptocurrencies: Jacob Hasselbalch, CBS, Denmark; Juan Giraldo, CBS, Denmark; Michael Friedewald, Fraunhofer ISI, Germany; and Deanna MacDonald, BLOC, Denmark. Smart Cities: Helle Zinner Henriksen, CBS, Denmark; Lasse Bundgaard, CBS, Denmark; John Rigby, Manchester University, UK.

[3] https://en.wikipedia.org/wiki/List_of_cryptocurrencies Accessed January 20th, 2020.

[4] www.coinmarketcap.com Accessed January 20th, 2020.

developed very rapidly. It is largely decentralized and non-hierarchical, and is exclusively driven by non-state actors (De Filippi and Loveluck, 2016).

There are five groups of actors driving cryptocurrencies. Firstly, the software developers and entrepreneurs who build the new coin or token, and create products and services supporting the infrastructure. Secondly, the "miners" who validate the transactions enabling their mathematical basis, earning a small fee[5]. Thirdly, the 'exchanges' such as Binance or Coinbase which act as 'places' for trading coins. Their might exert a lot of power by choosing to list and delist different coins. Fourthly, the users and buyers, who acquire cryptocurrencies as ways of saving, or buying specific products. Last, the "advocates" (celebrities, influencers, or engineers) who advertise and promote specific cryptocurrencies.

The capability of those agents is highly distributed within the system. Entrepreneurs, 'exchanges' and advocates are in a position of relative strength vis-à-vis users and miners. Regarding the capabilities of agents to induce or inhibit change, three specific forms of capabilities are needed: strong knowledge capabilities about software systems, cryptology and mathematics; physical capital in the form of strong computational capacity; and access to financial capital.

This brings us to the next issue, the governance instruments to drive and direct the change. It is important to understand that cryptocurrencies are largely shaped by the supply and demand side of a rapidly developing system of unregulated market dynamics. For that reason there are two types of governance instruments: those providing the technical solution, and thus creating new commercial products and services; and instruments focusing on the demand side, mainly shaping consumer behaviour. Regarding the first, the ecology of actors on each cryptocurrency agree on the rules and procedures of transaction and verification, enabling specific products and services. Regarding the second, advertising in social media as well as influencers and advocates campaigns (as discursive community mobilization devises) have been a preferred instrument for shaping consumer behaviour. Cryptocurrencies are governed on an ethos typically associated to software code development; therefore they are attractive to social groups that believe in alternative ways to state-dominated financial transaction mechanisms. Its anonymity also attracts those who want to escape the legal enforcing arm of the state (criminal activities). Yet, Facebook, Google and Twitter have restricted their advertising (in 2018) (see below).

The legitimacy of the social technical system around cryptocurrencies is determined by the degree of social acceptance of its outcomes and its processes; as well as by the forms of social contestation within (internal to) the socio-technical system. Given the digital nature of cryptocurrencies creation and use, the social acceptance of its outcomes and processes tends to be one and the same because blockchain creates a process that is itself an outcome. One of the main issues is how to create trust as a basis for social acceptance. Some authors claim that cryptocurrencies are "a shift from trusting people to trusting math"(Atzori, 2015) p.2. There are very strong libertarian philosophical standpoints associated to cryptocurrencies, typically organized in cyber communities who see the normative superiority and legitimacy of these types of currencies vis-à-vis state-controlled currencies. However the incident in 2016 (when an initial coin offering (ICO) based on Ethereum was hacked and more than 11,000 people lost their investment) resonated strongly within the community creating social contestation. In any case, experts in currency trading remain skeptical

[5] Yet, rapid technological change is transforming that, as new coins do not require miners.

about the mid-term sustainability of social trust in cryptocurrencies, given the speculative nature of most transactions[6].

The role of the state in crypto currencies has been so far very limited. Nevertheless, some first steps are taken in two different directions, namely regulating them; and exploring the opportunities. Some parts of conventional financial regulations already apply to cryptocurrencies' exchanges, and various states have been applying and enforcing that regulation to different degrees (Girasa, 2018). However, there is much 'wait and see' as most governments are just acting as an **observer** (monitoring course of events), and as a **warner** (issuing warnings urging investors to be cautious against possible Ponzi-like schemes)[7]. Beyond that, the state might also act as a **mitigator** trying actively to reduce the negative effects that arise as a consequence of this socio-technical system. Moreover, it might act as an **opportunist**, taking up the opportunity arising from socio-technical change. Sweden for example is investigating the possibility of launching an e-krona[8].

4.2 Primus inter Pares: Smart Cities

The second case is smart cities (or digital cities), which is a generic label for initiatives at city level taking advantage of digital technologies for public services like transport and energy (typically linked to sustainability goals), and increasingly for public health and social care. In Asia, some smart cities initiatives are creating entire new cities (Angelidou 2014). Yet, most often they are concrete initiatives within existing cities, typically launched in the form of pilot projects (using sensors, Internet of Things (IoT), new IT-platforms, etc) with a view of up-scaling to the entire city.

Smart city initiatives are a case of "primus inter pares" governance mode, a collaborative mode where the state takes a prominent role. Solutions are typically supplied by private firms, and often aim to engage users and citizens. The initiatives are largely (co-)financed with tax money, involve aspects of public procurement, interact with existing local public service provision, and are based on access to data. City-level or city-regional governments are those who tend to drive the initiatives, mobilise and connect capabilities, and most importantly, have the final decision about the choices of specific solutions.

Smart cities are not merely the introduction of digital technologies, but are characterised by multiple and inter-connected socio-technical systems' change. Therefore, those initiatives are characterised by diverse actors reflecting complex urban systems. Actors usually represent different sectors in industry (with large IT infrastructure providers as well as various SMEs as suppliers of specialised solutions), and different social groups like local citizen associations and civil society organisations, though the latter tend to be weakly involved. The "state" refers primarily to local governments (municipalities), and/or city-regional departments, often indirectly encouraged by national or supranational (EU) levels (Angelidou, 2014). The capabilities of actors to influence agendas and the provision of solutions differ greatly, with large private service or infrastructure providers mobilising strong technical capabilities and network resources to lobby for their solutions, while civil society organisations struggle to match societal interest with concrete capabilities to influence agendas. Of

[6] https://www.theguardian.com/technology/2018/sep/11/stable-coins-bitcoin-cryptocurrencies-tether?CMP=Share_iOSApp_Other Accessed on January 20th, 2020.
[7] "The EU Blockchain Observatory and Forum" talks about Europe staying in the front of the new technology. Read the press release: http://europa.eu/rapid/press-release_IP-18-521_en.htm Accessed January 20th, 2020.
[8] https://www.riksbank.se/en-gb/financial-stability/payments/e-krona/ Accessed January 20th 2020.

particular importance are lead users within cities who are able and willing to engage with the co-generation of digital solutions and to deploy them.

Smart city projects employ a range of governance instruments to influence direction of change. One important instrument is narratives, namely, the articulation and communication of future smart city visions. Other set of instruments have to do with forms of public procurement, public-private partnership contracts, and related, i.e. financing of new public infrastructure or buying in of digital service solutions, setting rules and frameworks that allow the application of certain technologies in the context of public services.

Smart city initiatives might not succeed without a minimum social acceptance of its outcomes and processes. The ambitious agendas of smart cities, with their cross functional portfolios and high level of transformative challenges for citizens, pose high demands on legitimacy. Learning costs are high, outcomes of experiments are uncertain, and expensive experiments might fail. Likewise the growing privacy concerns from handling of online data might become a central theme within data collection and commercialisation in the public space. For those reasons, there are high demands (and potential clashes) on the degree of social acceptance of the decision processes, meaning that the direction of smart city developments needs to be defined in a participatory process. In fact, the lack of roll out of initiatives has been attributed to a lack of such participatory processes (van Winden and van den Buuse, 2017). A major challenge in this respect is the perception of citizens that the material interest of large digital service providers and their access to data dominate the smart city agenda, which may overshadow citizen's concerns about the outcomes of smart solutions (particularly about personal data). Even if societal groups affected might occasionally voice opposition, the level of internal social contestation in smart cities initiatives tends to be rather low.

Following from the above, we can see that in the governance of 'primus inter pares' the state might act as a **facilitator**, seeking actively to make the process easier supporting specific dynamics of private and non-state agents. It might also act as a **lead-user,** initiating or supporting the creation of a market by acting as lead user and co-designer in order to find specific solutions to public needs. Thirdly, the state might perform the role as **initiator** of projects, directly using its own knowledge and resources to work in concrete ways for the transformation of the sociotechnical system in the city. In a similar vein, it is also a **promoter** of specific solutions, putting forward narratives and becoming an exponent of change in the city. As we have seen above, the state can become an **enabler of societal engagement**, encouraging the involvement of stakeholders in participatory processes to define direction of change. Last but not least, it can also play a role as **gatekeeper**, since the state (the municipality and/or the state) tend to own most part of the infrastructure, while also being the main buyer of the technology. This means it effectively controls access for other actors, opening up or closing down spaces for experimentation and transformation.

4.3 Oligopoly: Automated Vehicles

The third case is the socio-technical system of Automated Vehicles (AV), which is an example of oligopoly mode of governance. Automated (or autonomous) vehicles (AV) are vehicles with some degree of self-driving capacities. According to SAE standardization organization, there are six different levels of automated vehicles: from level 0 where the driver is in total control (conventional driving), to level 5 where the vehicle is completely self-driving and there is no driver (only

passengers)[9]. The technology is potentially disruptive and might introduce improvements in mobility systems (mainly optimizing the use of transport infrastructure, and accessibility gains). However, the ease with which consumers ultimately will come to use this new technology will determine the trajectory of this new socio-technical system. During the past few years the technology has developed rather quickly, and pilot tests have been conducted in many cities, most notably Helsinki, Gothenburg, and Boston (Taeihagh and Lim, 2018).

Automated Vehicles are a case of oligopolistic mode of governance. The development is largely driven by few economic actors form different sectors, mainly software-related firms like internet based services (Google), software and hardware providers (Apple), and providers of internet based individual transportation (Uber or DiDi). Conventional car manufacturers (Volvo, BMW, etc) have been following swiftly, as well as a growing number of start-ups (like SenseTime). The socio-technical system is organised hierarchically because these economic actors tend to be large industrial players, concentrated due to the network externalities of digital technologies and the rapid concentration in their respective industries during the past decade. There is naturally a competition among these actors to provide dominant AV solutions to the market, yet, they are few and they tend to collaborate in crucial matters like standard setting. For their part, as we will see later, governments have not been on the driving seat for the development of this socio-technical system, yet they have a significant presence due to their role in conventional driving and mobility systems (see below).

The capabilities of the agents governing this social technical system are actually highly concentrated in some few industrial actors. Those firms are either from the software sector with strong material and knowledge resources, they occupy crucial positions in the domain of internet- and data-based services; or they are from the automotive sector seeking to adjust their traditional paradigm to the data-based autonomous model. State actors like municipalities and national authorities (governmental actors including transport and road safety authorities, and transport planners) for their part, are not on the driving seat, but are following events and trying to anticipate regulatory issues. Other actors like bicycle associations, or civil society associations representing the elderly, handicapped, etc are not as active shaping the new socio-technical system, as their capabilities are lower. Hence, the distribution of agents' capabilities in the system is concentrated in few actors (the software and automotive industries, and service providers). Yet, there is an important level of dependency: the AV firms depend on state actors' regulation, authorisation and transport planning, as well as on societal acceptance (see below).

Actors use different governance instruments for the creation and change of the automated vehicles socio-technical system. One of the most relevant is the creation of technical standards and software protocols for the communication between vehicles (V2V) and with infrastructure (V2I). The combination of both technologies (automated and connected vehicles) offers additional functions for mobility solutions. Agreeing on protocols and setting the standards at international level is occupying the attention of producers. Likewise, another important governance instruments are the creation of experimental spaces. Pilot projects and test beds have been launched by private firms in some university campuses or cities, and have been allowed by temporary exemptions from regulatory authorities. In relation to that, another key instrument is regulation. Local and regional-national authorities are testing some first steps into the regulatory framework, which comprises issues of traffic safety and territorial planning. Last, but not least, a paramount type of instrument is

[9] SAE standard J3016_201806 of 2018-06-15 https://www.sae.org/standards/content/j3016_201806/ Accessed January 20th, 2020.

discourse-based. Producers, journalists and engineers have developed future-oriented narratives about the advantages of automated vehicles, aiming to promote their social acceptance.

This brings us to the next point, about the legitimacy of this socio-technical system. Surveys about the social acceptance of automated vehicles are somehow unclear about the widespread of social acceptance, because one third of respondents is in favor, one third undecided, and one third skeptical (Dütschke, et al., 2017). There seem to be growing concerns about road safety issues and data privacy in machine-human interactions (Stilgoe, 2017) (Habibovic, et al., 2016). However, the social contestation remains unarticulated and with little voice. This might change with the gradual introduction of AVs in city streets and roads.

Traditionally, the field of road and vehicle safety is organized in a complex set of arrangements of private and public nature, where the role of the state plays a fundamental role with its regulatory power to define the limits and forms of road safety and liability, and its role in transport planning and infrastructure-building. For that reason, in the process of changing the sociotechnical system towards automated vehicles, the state remains an important **gatekeeper**. State actors have allowed the introduction of pilot schemes in cities and roads, by experimenting within regulatory exemptions. Furthermore, the state is largely acting as a **facilitator** because it is in charge of the physical infrastructure planning. Rolling out AV socio-technical system requires new classification of driving zones, new physical traffic signs and adequate long-term transport infrastructure investment plans. Last, but not least, the state acts as well as **promoter**, pushing and acting as a champion for specific dimensions, most typically the development of shared services (e.g. AV-shuttles).

4.4 Command and Control: Nuclear power

The fourth case concerns the governance of nuclear power, producing electricity by means of controlled nuclear fission. The commercial use of nuclear power plants commenced after the Second World War following suggestions of “Atoms for Peace”. Until then nuclear energy had been solely used for weapons of mass destruction, causing the horror of Hiroshima and Nagasaki attacks. Seen as a reliable source of electricity, some countries began building nuclear fission reactors in the late 1950s, and it has grown ever since, yet with a little decrease since the Fukushima accident (already up to same level). However, this development has experienced important ups and downs along different aspects, the most important of which are the fear of nuclear accidents; the safety problems with nuclear waste; the high capital investment costs of nuclear power production (mainly due to increased safety requirements); the envisaged scarcity of uranium; and the rapid rise of new sources of renewable energy which are cheaper, safer and more environmentally friendly (Müller and Thurner, 2017). In 2017 there were around 448 active nuclear power reactors in 31 countries, generating approximately 10% of the world’s electricity (IAEA, 2018). However, this is unevenly distributed across countries.

The social technical system of nuclear power is a case of ‘command and control’ mode of governance. Whereas the dynamics and types of agents of change might differ between countries (see section 6), the dynamics of change in this social technical system are overwhelmingly driven by the state. This is so for several reasons. First of all, because nuclear power is capital intensive and has high unit costs, requiring heavy investments in large facilities with very long timeframes for recapping the investment. This means that most nuclear power producers are state owned enterprises and run with important public subsidies (not only direct, but also indirect in the form of

compensation and insurance for private actors of possible damages) (Linares and Conchado, 2013). Secondly, because the state makes decisions on issues about health and safety concerns, which are very relevant for nuclear power (Shiroyama, 2015). Last, nuclear power is a highly salient issue in inter-national politics with well organized inter-national knowledge cooperation sharing expertise and data; as well as geo-political dimensions of defence and security. Hence, this socio-technical system is organized in a hierarchical way because very few actors, mainly utilities and/or directly the government itself, are dominating the decisions (even if with some occasional tensions).

The capabilities of the agents of change are distributed. Nuclear power production is in the hands of few public or semi-public firms (utilities) which have very strong financial capital and technical knowledge capabilities. Access to the electricity grid is essential, and is typically addressed by strong relations between the government and the utilities and/or with regulations that guarantee priority access. The state has very strong capabilities too in terms of financial resources, as well as knowledge resources (in public research centres, specialized agencies, and/or the military). Likewise, civil society organizations have strong capabilities with important resources in terms of mobilization of public opinion. It is important to mention the relevance of international associations supporting openly the expansion of nuclear power, as well as others contesting and opposing its deployment.

Legitimacy is a key dimension in the governance of nuclear power social technical system. In most democratic countries there are surveys indicating the degree of social acceptance. Whereas there are different views on that, in virtually all the countries public opinion seems to be quite sensitive to nuclear disasters, like the recent Fukushima accident. There tends to be a historical oscillation in terms of acceptance as well, with waves of opposition and indifference throughout long periods. Due to the centrality of the state in the change of this social technical system, legitimacy is highly related to the legitimacy of the procedures and political processes for governmental decision-making. This is to say that, the highly political nature of changes in nuclear power is strongly tied to the outcome and process legitimacy of the political system in question. The strong social movements opposing and contesting the use of nuclear power have enjoyed substantive endorsement in many Western European countries. Particularly relevant are the cases where initial state decisions to phase out the use of nuclear power have been revoked, and the state has decided to maintain current levels or to expand the construction of further fission plants. Antagonistic positions across the aisle in favour and against have tended to mobilize passionate debates and social controversy.

Taking everything together, the role of the state in the mode of governance of the nuclear power socio-technical system is very central. However, the capabilities of agents in this socio-technical system are distributed because civil society has strong capabilities too, so the state's final ability is highly dependent on legitimacy of change, and not only on the exercise and control of the instruments of change. From the above it can be observed that the state has several roles. It acts as a **moderator** of societal attitudes, and of utilities' interests (and their shifts); it also acts as a **promoter** because it is an active proponent and exponent through specific narratives about the decisions and direction of the socio-technical system. Likewise, it has the role as an **initiator**, because it identifies opportunities and put its own resources to work (among them using large funding) into a specific direction defined in a political process. Fourth, the state acts as a **guarantor**, as the state secures actively and directly operations against financial and/or security and safety risks. Last but not least, the state is also a national and international **watchdog**, actively ensuring that agents comply with collectively defined norms (regulations and standards), not only at national level, but also at international level (for health and safety standards, as well as for geopolitical security interests).

5. Summary and Discussion: The various roles of the state

The analysis of the illustrative cases across the four modes of governance has allowed us to identify and conceptualize various roles of the state in the transformation of socio-technical systems. Box 1 summarizes the 13 roles of the state, with their corresponding definitions.

Box 1: Summary of the different roles of the state, and their definitions

Observer: the state monitors the course of events, following up the developments and trends in the socio-technical system.

Warner: the state identifies potential risks to users, citizens and institutions; develops and communicates a warning narrative around those risks.

Mitigator: the state tries actively to reduce the negative effects that arises as a consequence of socio-technical change.

Opportunist: the state takes up the opportunity arising from socio-technical change, becoming itself an active beneficiary of the new social technical system for specific purposes.

Facilitator: the state actively seeks to make a process easier by supporting specific dynamics of other agents' change initiatives.

Lead-user: the state initiates market creation by acting as lead user and co-designer in order to find specific solutions to public needs.

Enabler of societal engagement: the state encourages actively the involvement of stakeholders in participatory processes to define direction of change.

Gatekeeper: the state actively controls access for change agents, opening up or closing down spaces fo"our analysis"r experimentation and transformation.

Promoter: the state acts as a champion, proponent and exponent of change in the sociotechnical system.

Moderator: the state acts as an arbitrator or negotiator between different social and political positions among agents regarding the direction of transformation of a sociotechnical system.

Initiator: the state identifies early on some opportunities, and pro-actively uses its own knowledge and resources to work in concrete ways for the transformation of the sociotechnical system.

Guarantor: the state actively and directly secures operations against financial and/or security and safety risks.

Watchdog: the state actively ensures that individual agents in a sociotechnical system comply with particular collectively defined norms.

Our analysis indicates that each of the four types of governance modes exhibits particular mixes of different roles of state. In other words, role mixes vary across modes of governance in a significant way. Table 2 summarizes them.

Table 2: Summary of different roles of the state across modes of governance

Mode of Governance	**Role of the State**
Self-regulated **(Cryptocurrencies)**	Observer Warner Mitigator Opportunist
Primus inter pares **(Smart Cities)**	Facilitator Lead-user Initiator Promoter Enabler of societal engagement Gatekeeper
Oligopoly **(Automated Vehicles)**	Gatekeeper Facilitator Promoter
Command and control **(Nuclear Power)**	Moderator Promoter Initiator Guarantor Watchdog

Source: own elaboration

When taking one by one each of the different roles, we see that some roles are present in multiple modes of governance. For example, we can observe that the state acts as a 'promoter' in 3 out of our 4 illustrative cases (Smart Cities, Automated Vehicles, and Nuclear Power). Yet, what is interesting is the way in which those roles are combined in specific mixes within each mode of governance, telling us about the complexity of state role in socio-technical systems, and about the fact that the state is not a uniform actor, but assumes several roles at once.

Naturally, there is a word of caution here, as our discussion is based on one illustrative case for each mode of governance. Firstly, we cannot claim that these specific role mixes are static patterns that will systematically appear in other cases within each mode of governance. Variation of these mixes will most likely happen within the same mode of governance. This calls for the second word of caution, namely, that the latter can be formulated as an empirical question, as additional analysis will be needed to further qualify our conceptualizations and to examine if regular patterns of state role mixes emerge across cases within the same mode, or not. What is important is that our four illustrative cases

have provided clear indications that are worth considering in this pre-study (Swedberg, 2012) given the early stage of studying the roles of the state in the governance of socio-technical systems' transformation.

6. Conclusions and Future Research

Recent calls for more transformative and problem-oriented research and innovation policies have tended to severely simplify the role of the state as market-correcting or market-creating. As we saw in previous sections of this paper, this simplification is partly because these recent calls have not related to the rich literature about the governance of science and technology, and partly because the transformation they seek is mainly oriented towards markets rather than to the grand challenges afflicting socio-technical systems. In order to address this important blind spot, this paper builds further from previous literature in order to provide an informed understanding and conceptualization of different roles of the state in the governance of socio-technical systems' transformation.

Therefore, the contribution of this paper is three-fold. Firstly, based on the analysis of 3 specific questions in 4 illustrative cases, this paper identifies and conceptualizes 13 different roles of the state in the governance of socio-technical systems' transformation. This variation is a relevant aspect to take into consideration when examining a specific possible role that the state might take in order to influence the transformation of socio-technical systems.

The second contribution of this paper is the understanding that within each of the four governance modes, the way in which the state can define its different roles depends on a number of dimensions. The 13 different roles of the state that we have identified and conceptualized are related to three important analytical elements, namely, the distribution of capabilities inside the socio-technical system, to the choice of policy instruments, and to forms of social legitimacy; not only just to the particular position of the state as driver or not-driver in the governance of the system. Hence, the conceptualization of 13 different roles serves to understand that the transformative agency of the state is leveraged or constrained by modes of governance in significant ways, as we observed variation of state roles in the 4 modes of governance.

This brings us to our third contribution, namely, that the 13 different roles are combined in various mixes. In our analysis of four illustrative cases we have identified 13 roles, which are combined in different mixes. Hence, the conceptualization of 13 different roles serves to understand that the transformative agency of the state is leveraged/constrained by the modes of governance, and that it is also ultimately exercised through specific mixes of roles which might vary across cases, since we are not claiming that the mixes we have found follow fixed patterns.

We might now consider the usefulness of the approach put forward in this article, both for analytical and for policy purposes. From an analytical perspective, the current approach, and its further developments should be useful as a tool to examine the specific roles of the state in transformation processes with a multiple step process. At a first step, researchers can analyse what type of governance mode characterizes a specific socio-technical system. Thereafter in a second step, the researchers can consider examining in more detail the three analytical dimensions shaping the nature of change of socio-technical systems suggested in this paper: the distribution of agents' capabilities, the type of policy instruments used, and the degree of social acceptance to outcomes and processes. Understanding the governance mode and the nature of the change process allows the researcher to look at the mixes of roles that the state performs in that particular mode of governance, contrasting

them with those identified in this paper. These steps will provide a more embedded approach to unveil the complexity and mixes of roles of the state in the governance of social technical systems' transformation, and advance our understanding of governance processes for addressing grand challenges.

From a policy-making perspective, the current approach might be useful in the design of transformative STI policies. Sometimes policy-making takes place by formulating individual policy instruments in a rather isolated manner, without taking into account various forms of state action, or the complexities of governing change in socio-technical systems. Equally, sometimes governments formulate ambitious transformative policies across a range of missions without taking into account that instrumentation, mobilisation and coordination has to correspond to the underlying properties of the socio-technical system. Therefore, policymakers might use this approach to reflect about the different roles of the state in specific socio-technical systems as an intermediary step before defining specific policy instruments (like funding or regulation). Likewise, they might consider the different roles of the state when defining issues of organisational coordination across different public administration units and across different organisational stakeholders. Transformative change for addressing the complexity of grand challenges might require substantial organisational coordination issues, and therefore a more explicit, conscious approach to understand governance conditions might help introducing such contextual approach to policy-making.

Naturally, our analytical framework has some limitations. First, the state might accidentally inhibit change. Even if visions and missions are clear and well formulated, the state might not be able to act according to the requirements of missions due to important limitations of its own organizational capacity. This brings the question of organizational capacity to the fore, understanding that the transformation of sociotechnical systems is a complex phenomena calls to consider issues of organizational capacity of governmental actors (Borrás, 2011) as well as other actors, particularly when considering introducing reflexive governance in directional processes of transformation (Lindner, et al., 2016) and when building capacities to manage emerging knowledge-based technologies in a tentative manner (Kuhlmann, et al., 2019).

Second, it is important to understand that the state might not always invariably be transformative. Our four cases looked at the role of the state in processes of socio-technical systems' transformation. Yet, the concept of 'transformation' was not unfolded (we did not discuss types of transformation), and we do not automatically assume that the results of transformations are positive. In the future, our framework can be used to look at different forms of transformations (disruptive, incremental, including no-transformation), and at their different consequences (positive or negative).

Regarding a future research agenda, we might suggest at least two important lines. The contribution of this paper is to contextualize the role of the state in socio-technical systems' governance, and in so doing it has payed attention to its variation across four modes of governance. Hence, the first line for a future research agenda will study variation ***within each mode of governance***, particularly studying cross-country variation, cross-time variation, and multi-level variation. We examine these three one-by-one. Cross-country variation within each mode of governance is important to consider because the role of the state is defined differently across states by the specificities of constitutional, historical and cultural features of each individual state. Furthermore the governance mode differs because countries have very different capacities, specific technological trajectories, certain institutional settings, etc. For example, the roles of the state in the governance of nuclear power in the UK might be different than in Germany. Such research efforts would build further on the empirical cross-national comparative tradition of the institutional and evolutionary economic literature. Likewise, it would be relevant to

study cross-time variation within each mode of governance, for example the role of the state in the governance of nuclear power in the UK in the 1950s is very different than in the UK in the 2010s. Last but not least, the multilevel interaction between local, regional, national, and international levels of government within each mode of governnce is also crucial dimension for future analysis. This is so because some socio-technical systems might be more internationalized than others (in terms of the relevance of inter-national dynamics in their governance, or their local/spatial dimension).

A second important line for future research agenda might consider issues of ***time and the change of the roles the state plays over time***. Understanding that some transformations might be more rapid than others, we might analyse the role of the state, as well as different dimensions of governance of social technical transformation in terms of the different speeds and paces of change (Weber & Havas). For example, many of the socio-technical systems' transformations associated to digital technologies are happening at a faster pace than others. It is worth considering the role of the state, as well as issues of distribution of agents' capabilities, instrumentation, and legitimacy related to the pace of change, as well as the negative consequences for the social groups left behind.

All in all, our paper aims at opening up a research agenda that takes the role of the state in its transformative research and innovation policy-making in a much more embedded approach, one that looks into the diversity of roles, in the modes of governing socio-technical system's transformation.

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