For the love of complexity:

Governing technological innovations

Inaugural lecture delivered in abridged form on the acceptance of the Chair of Political Science, especially Governance of Complex and Innovative Technological Systems

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1 INTRODUCTION

Ladies and gentlemen, tonight, we will concern ourselves with the simple question I've been asked many times since coming to Bamberg: what are you doing here? Or, in more formal terms: why should political scientists concern themselves with complex and innovative technological systems? What is the political dimension of technology? We will try to find some first answers to these questions. Naturally, we can only hope to scratch the surface in the limited time available for an inaugural lecture but let's try regardless.

At first sight, we can already see some clear linkages between technology, policy and politics, if only because certain policies promote or restrain technological development. It is generally reckoned that Bavaria features one of the most advanced research and knowledge infrastructures in Germany, if not in Europe.[1] This does not only concern sectors traditional to Bavaria such as the automotive industry or mechanical engineering, but also biotechnology, technology for health care and IT. The strength of this infrastructure does not only derive from enterprises doing well and investing wisely, it is also because the Bavarian government has targeted and sustained policies towards promoting research and development, investing approximately 15% of its annual state budget in research and development. The complete research and development budget, brought together by both the private sector and the State, adds up to about 12.2 billion euros annually. This amounts to 3.2% of the Bavarian GDP, which is, which is quite above the German (2.8% in 2014) and European average.[2]

Innovation and technology is something that the state as a whole benefits from – for example directly through sales and taxes, or indirectly through the creation of jobs and cluster-effects. As such, there are ample reasons for politicians and administrative to develop policies in order to keep research and development going. Koschatzky & Stahlecker identify at least 12 major technology and innovation policy programs in Bavaria, aimed at (among others) public venture capital companies (e.g. Bayern Kapital), establishing and reinforcing regional clusters (e.g. BioMünchen), promoting research collaboration between public research organizations and the private

[1] Koschatzky & Stahlecker (2010)

[2] Bayerische Staatsregierung (2011)

sector (e.g. Bayerische Forschungsstiftung) and more.[3] One notable observation we can make about Bavaria is that the development of technology takes place in clusters of both private and public entities, such as schools and research institutes. The State of Bavaria considers these clusters as pivotal to Bavaria's economy and many policies are geared towards strengthening those clusters. In other words, technological innovations are as much a matter of policies and politics as it is about hiring good engineers. Let's examine that argument in closer detail.

I will first make the argument that technological systems can't be understood without their social and political contexts. We should therefore talk about coupled socio-technological systems. I will then demonstrate how such coupled socio-technological systems feature complex properties that prohibit straightforward attempts at governing them.[4] I will conclude the argument with a discussion of what these ideas require from us academics, students and practitioners – and will make the argument that complexity is something we ought to embrace.

2 WHY TECHNOLOGY?

As you already could suspect from the introduction, there is a strong economic argument for the development of technologies: it brings in jobs and economic growth and tends to contribute to the welfare of a state. Indeed, the official viewpoint of the Bavarian government is that Bavaria needs to be strong developing high-tech products and services in order to keep competing with other countries, if only because Bavaria doesn't have any significant stock of raw materials to export.

So technology it is. The reasoning goes that large-scale innovation is a necessary but risky endeavor because it is unclear whether there will be a return on investment for individual companies. There are many

[3] Koschatzky & Stahlecker, 2010: 17

[4] There is a great temptation to display scientific strength by flooding the audience with huge numbers of references and in-depth analyses of current debates about complex systems. I would rather focus on some core ideas and practical examples. For a more thorough overview, please refer to Gerrits (2012). Also, I'm indebted to the many scholars before me who have cleared many pathways. I just realized it is exactly 25 years ago that Walter Kickert held his inaugural lecture entitled 'Complexity, self-steering and dynamics'. How time flies.

failed attempts for every successful technology. Also, it can be expected that part of the research output spills over to other firms, who imitate the innovation without carrying the burden of the investment[5], e.g. through reverse engineering. This is a clear case of market failure.[6] But if research and development contributes to the national economy, it can be reasoned that governments should step in to mitigate the risk using subsidies – after all, such subsidies could (potentially) act as multipliers for income.

Subsidizing research and development, in particular when there is a promise of direct utility, is therefore relatively little controversial and gets support from left, right and center. For example, the Bavarian government started subsidizing regional innovative clusters, such as the IT-sector in Munich, which in over a decade lead to an increase of innovative capacities by 4.6 to 5.7 percentage points while research and development expenditures by private enterprises decreased by almost 20% on average during the same period[7]. In other words: these cluster-oriented policies had achieved exactly what was expected from them. Or, to use another example, the European Commission justified spending 80 billion Euros on research by saying that it is "[...] seen as a means to drive economic growth and create jobs, our subsidy program has the political backing of Europe's leaders and the Members of the European Parliament. They agreed that research is an investment in our future and so put it at the heart of the EU's blueprint for smart, sustainable and inclusive growth and jobs."[8]. In short: there is an economic or even financial motive to engage with technological innovation.

Having said that, the market-failure argument is undermined by empirical studies that show that subsidies are relatively ineffective in promoting technological innovations. Gaillard-Ladinska and colleagues[9] carried out a meta-study and found out that a "[...] reduction of R&D subsidies only leads to 1-2 percent more private R&D investment. This suggests that in the absence of subsidies, most private investments in R&D would still have been carried out."[10]. That

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[5] Frenken (2016)

[6] Arrow (1962)

[7] Falck, Heblich, & Kipar (2010)

[8] https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020 retrieved on May 29th, 2016

[9] Gaillard-Ladinska, Non, & Straathof (2015)

[10] In: Frenken (2016)

is actually something many parties are aware of. The economic argument is therefore not the only driver behind technological innovation.

Another, important, reason for technology is what Bent Flyvbjerg calls 'frictionless society' or zero-friction society[11]. This constitutes a society where we can achieve more with less effort, a society where we have liberated ourselves from the constraints of space and time. Naturally, technology plays a very important role in this. We may be looking for easier ways to do our dishes or easier ways to travel to distant countries or to the highest mountain tops or easier ways to do complicated calculations or better ways of saving lives in the hospital. We even spend precious brain capacity to build apps for our smartphones so we can watch pictures of cats on the internet at 2am instead of sleeping.

Once we have embarked on that road towards technologies that promise lesser friction, we need other technologies to achieve that. I think that most people will agree that smartphones are making live a little easier in a number of ways, in particular when you ought to study but really want to see those cats online, but the construction of smartphones requires rare metals to be produced. These are hard to extract so we need specific technologies to extracts those raw materials. The tools needed for that also require specific technologies, and so we embark on a route where we need technology in order to make technology that will make our lives a little easier. In doing that, we create a system of interlocking technologies.

I don't know if we are creeping closer to that Utopia of being independent from space and time, and I don't know if it would be a desirable goal in the first place. What matters to me is that it is an important driver behind technological development. But still, money and convenience do not explain all the reasons for that development.

The third reason why we invent and use new technologies is often overlooked or goes unmentioned but I believe it is a very important one: we do it because we want and can do it. Or, in the words of Karen Frick, because technological progress delivers us rapture and the sublime, and that is a goal in itself[12]. For example, there are many good reasons *not* to build a tower with a height of almost 900 meters but yet the Burj Khalifa is there because, as Sheikh Mohammed bin

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[11] Flyvbjerg, Bruzelius, & Rothengatter (2002)

[12] Frick (2008)

Rashid al Maktoum said, he “wanted to put Dubai on the map with something really sensational.”[13]
Thus, as Frick asserts, developing new technologies lead us to believe that we have achieved progress and that has become a value in itself, not to mention an important factor in politics: “The idea of progress creates a political dimension that can capture the imagination of political leaders and the public. This aspect of the technological sublime is [...] a political tool that can be used to bolster position statements, increase public awareness and to fulfil personal interests.”[14]. Indeed, it is within the realm of politics where such ‘monuments’ are hatched. Indeed, the perception of progress can actually help to gather public support and foster creativity but it can also easily lead to loss of control over the project or technology (ibid.). This is particularly an issue when the risks are shifted to the government, which then has to use tax money to salvage the project or program.
For example, the German MAGLEV rail project was not only intended as a faster means of traveling between major cities (the zero-friction argument), not only as a way of demonstrating the technological prowess of the German industrial sector (the economic argument), it was done because it could be done. There had been ample warnings by the Scientific Advisory Council of the Ministry not to pour money into this project, yet it took the restructuring of Deutsche Bahn before the real risks were revealed and the argument that it was ‘good because we could’ was hollowed out.
By now, it should be clear that there is a strong relationship between technology as an artefact, the meaning we assign to it and the things we do in order to develop technology. In fact, we can’t understand technology if we don’t understand the social practices it is connected with. Let me use an example to demonstrate that point.

3 THE ICE-4: TECHNOLOGIES AS NEGOTIATED OUTCOMES

To most people, figure 1 will just feature a picture of a brand-new train, in this case the German ICE-4 high-speed railway train. However, to me, it is primarily a technological artefact embedded in

[13] Roth & Roth Clark (2014)
[14] 2008: 242-243

social and political ideas and practices. Let's investigate that in more detail.

Figure 1: ICE-4 High-speed trainset being tested. Photo courtesy of Siemens Mobility.

Let's take a look at the front of the train. The shape of the cab, the coupling and coupling doors, the size of the window pane etc. are strongly determined by our understanding that head-on train collisions are a bad idea. Therefore, we generally agree that the front of the train should act as a passive safety device to absorb at least part of the energy released during collisions, should they happen. This is consensus is set in European regulations that are regularly adjusted to reach higher safety levels. Newly designed railway vehicles are only admitted to the European railway network after extensive homologation, which includes tests for crashworthiness to see whether the impact protection system functions properly. That is an agreement made on the European level by the European Commission (article 26 of Directive 2008/57/EC, to be precise).

Homologation is not a simple task. It can take years and millions of Euros to have a particular type admitted. It brings safety, it costs money and time. Consequently, the setting of standards is not a straightforward technocratic process. It is not just a matter of building the safest trains because there are ample trade-offs: weight versus speed, dimensions of the structure versus the loading gauge, costs versus effectiveness, higher standards vs. what the industry can currently deliver. As such, the standards are the negotiated result of all parties involved who settle – temporarily – on certain agreements that they honor their possibilities and stakes.

The European homologation process itself is also governed by multiple parties; national safety authorities, the European Commission and the European Railway Agency, the International Union of Railways, the national infrastructure providers, the operators, and manufacturers all play a role in this. Each actor has its own ideas about what is feasible and necessary and thus attempts to push its main points forward. In the past, each country had its own procedures and standards. That is slowly coming being harmonized. If actors from the European Member States have their own standards and procedures, they quite understandably believe that theirs are the correct ones. For example, representatives from Deutsche Bahn commented on the homologation process that there are "[...] certain differences in technical 'philosophy' between French and German Railway technology (which is based in decades of only national developments [...]"[15] And the European Railway Agency itself points at the ambiguous network of actors involved, saying that much complications arise not out of technology per se but out of "[d]ifferent roles and responsibilities allocated to the actors in the different EU Member States that hinders mutual trust and therefore mutual recognition."[16] In short: what we are looking at is not just a cab front, it is the negotiated outcome of the ideals and technical feasibilities as brought forward by the many parties involved in homologation.

The thrust towards harmonization is part of a broader development in the European Union, namely to create a single European market. For the railway sector, this means that there a slow evolution towards a full internal market for railway services and equipment. The European Commission assumes that a single railway market will lead to better services to passengers and frictionless transport of goods throughout the Eurozone – the arguments of economy and zero-friction, once more. Naturally, a single market requires harmonization of the technical and operational dimensions of rolling

[15] Hoppe, Matschek & Müller (2006)
[16] European Railway Agency, 2011: 45

stock, as well as the infrastructure to run trains. The more uniform the equipment, the better operators will be able to operate everywhere in Europe. As mentioned above, there used to be 14 distinctively different standards in operation in the European Union alone. Harmonization is arranged by, among others, Directive 96/48/EC. Part of that is the development and implementation of the European Rail Traffic Management Systems or ERTMS. ERMTS arranges for a standardized dedicated mobile phone network called GSM-R, and a standard for operational safety, train–track communication and unified cab control called European Train Control System or ETCS.

Setting the requirements within the ERMTS framework is a thoroughly political process. ERA, the agency overseeing the development and implementation of ERMTS on behalf of the European Commission, doesn't superimpose its standards on the member states. In fact, much of what it presents to the European Commission has been developed by ERA's stakeholders, which includes members from various ministries and regulatory bodies of those member states, and companies such Alstom, Thales and Siemens Mobility.

While standardization and harmonization may sound attractive, ERMTS had received a lukewarm response from the Member States. For long, lack of political support meant that the standard was not really adopted. Ultimately, much of the support appeared to depend on money. Between 2007 and now, about 800 million euros from the EU budget has been earmarked for the development and implementation of the standard, to be matched by member states and industries. Right now, the standard is slowly implemented in the various railway systems across Europe, and beyond.

However, the implementation is far from straightforward, even when political support is in place. ERMTS may be a standard but practice shows that there are still incompatibilities between manufacturers. For example, Stoop and colleagues demonstrated dysfunctional incompatibilities in the equipment from Alcatel and AnsaldoBreda in Belgium and the Netherlands. This was partly due to the different ways in which the governments of both countries thought that such innovations should be developed, with Belgium going for a traditional approach and the Dutch government hell-bent on a Public-Private Partnership mode. Indeed, the PPP had become the goal in itself rather than a means to implement the standard and safeguard seamless travel between Belgium and the Netherlands[17]. The result was a costly but not fully functional technical system that took another few years and additional investments to run properly.

The design of the ICE-4 is not only governed by EU regulations concerning safety and interoperability. Accessibility of trains, the dimensions of the doors, and the buttons to operate them are strongly determined by certain accessibility standards that function as legal obligations. By law, trains need to be accessible for people in wheelchairs. The dimensions of such wheelchairs are arranged in the ISO standard ISO/TC 173/SC 1. ISO is the International Organization for Standardization, an international standard-setting body in the shape of an NGO. It is composed of representatives from various national standards bureaus or organizations who meet frequently to set such standards.

This particular standard concerning wheelchairs was set in an international agreement in 1980 between 24 countries, including most of the European countries, the USA and Canada and China, and was chaired by the South African Bureau for Standards. This is because we, as a society, have an institutionalized norm that people in wheelchairs or that are impaired otherwise need to have access to public transport. Again, we are looking at a social and political process that has lasting impact on the technological artefact.

So far, we have focused on the setting of technological standards that determine what our train looks like and how it operates – and I apologies for giving such a detailed account of dry rules and regulations. But there are also other practices at play here. In talking about these regulations, we should not forget about our social practices regarding traveling. If anything, the operator Deutsche Bahn and the manufacturer Siemens want to make train travel an attractive activity. They do so by conveying an image of comfort and luxury through design requirements and a narrative about the nature of the design. Traveling by train, they tell us in the press statement, is not just a utilitarian activity that you need to undertake to get from A to B, it is something you should enjoy and look forward to. It should give you the impression that you can travel effortlessly and comfortably in comparison to other modes of transport. Consequently, the design features big windows and air conditioning and a galley where you can

[17] Stoop, Baggen, Vleugel & Vrancken (2008).

have a bite or a drink, and WiFi-antennas so you can go online while traveling.
It is easy to dismiss such words as marketing talk but that would be beside the point. What I want to argue here is that we, in our society, have a more or less coherent understanding of what constitutes a good way to traveling. Without that, you could just bolt seats in the train and be done with it. But there is a clear understanding that it is necessary to attract passengers because people have a choice between different modes of transport, some of them less efficient or more polluting than others. That understanding leads us to design rolling stock with attractive features. This is not exclusively tied to the ICE-4. It only takes a quick survey over recent tender requirements for local and regional railways to see that Passenger Transport Executives demand all kinds of features in order to attract passengers even to the humblest of railway connections.

4 COUPLED SOCIO-TECHNOLOGICAL SYSTEMS

With the knowledge we have now, we understand that at any point in time the faith of a certain technology is strongly influenced by the political and administrative considerations and actions, and by the social beliefs and conventions of that particular time. In other words, we need to understand a technology not just as a stand-alone artefact and not just as an artefact in a given environment but as a coupled socio-technological system of social and technological elements. The shape of a future technology depends strongly on what we currently believe is necessary, desirable, and feasible. This point of departure is advocated by, among others, Wiebe Bijker[18]. As he argued, political power is of tremendous importance in deciding the faith of socio-technological systems. Not every social actor is equal, formal hierarchies and other forms of power relationships matter a lot. Consider, again, the relationship between ERA, the European Commission, the Member States represented in ERA and in the European Parliament. It is not hard to see that these actors are not equal in the powers they exert, which is reflected in the policies (e.g. single railway market) and the standards adopted. In short: each technological system is heavily embedded in social and political

[18] Bijker (1995)

practices. These coupled socio-technological systems have certain characteristics that are conveniently summarized under the header ‘complex’. I would now like to discuss some of the main properties of that complexity.

5 PROPERTIES OF COMPLEXITY

Complex systems have quite a few interesting properties that set them apart from complicated systems. This is not the place to present an exhaustive list[19]. For now, I want to highlight some of the most important ones: path-dependence, non-ergodicity, equifinality and multifinality, and self-organization.

To start with the first: There is a great deal of path-dependence in technological systems. Path-dependence basically tells us that the resources necessary to do something entirely new are such that it is more profitable to keep doing what you have been doing instead of doing something new, even though the new thing may deliver better returns in the long run than the thing you are doing.[20] [21] [22] In this, we are impeded by lack of foresight, i.e. we are unable to make precise predictions of which alternative is the better one.[23] If a company is very good at building cars with internal combustion engines, it is very likely that its next innovation is going to be a car with a different engine.

Path-dependence doesn’t only occur in single companies or technologies, it also holds true for cities, regions and countries.[24] [25] For example, Hidalgo and colleagues showed that countries develop their economy by diversifying into export products that are closely

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[19] I’ve presented the properties of complex systems and related governance issues in among others Teisman, Van Buuren, & Gerrits (2009) and Gerrits (2012). A critical discussion of the state of art in governance and complexity can be found in Teisman & Gerrits (2014).

[20] Arthur (1994)

[21] David (1985)

[22] When applied to social science at large, path-dependence often entails that history matters, which is a truism. The economic, narrow, definition still is very useful for social science. See e.g. Gerrits & Marks (2008) for a discussion and application.

[23] E.g. David (1985) for the famous example of QWERTY

[24] Neffke, Henning, & Boschma (2011)

[25] Boschma, Minondo, & Navarro (2013)

related to products they already export.[26] This is not just something that boils down being good at something continuing to be good at it, it actually relates to the whole physical and social infrastructure concerning that technology. The product is produced in a certain context, under specific policies, institutions and governance arrangements. Germany, for example, has a strong legal tradition where the space of possibilities is fairly well-defined. That has its impact on the development of technology, particularly so because technology can change quicker than rules and regulations. Promoting a culture of innovations therefore requires structural transformations.[27] There are advantages and disadvantages to path-dependence. A company, country or region will be king as long as there is a niche for the particular technology it is producing. The downside is that one can be doomed to run a dead-end street because there is simply no real opportunity to change. Thus it is that the US and other countries such as Norway, Italy and the Netherlands in the JSF-alliance keep pouring money into the F-35 fighter jet despite the fact that it has been delayed for years, is facing massive budget overruns and has a compromised operational role because it was originally conceived in a time when drone warfare was not even a remote possibility.

If coupled socio-technological systems following certain trajectories through time, and if these systems are determined by the specific circumstances or conditions at the time of developing, then it doesn't require much imagination to understand that chance plays an important, not to be underestimated role in the shaping of such trajectories. For example, the interim evaluation of the Betuweroute freight track between Emmerich and the Port of Rotterdam coincided with the disastrous fire in the Mont Blanc tunnel. Subsequently, the Dutch Parliament demanded a redesign of the tunnels in the railway project to include all kinds of new firefighting equipment. This came at massive costs.[28]

Had the fire occurred a year later, or not at all, this technology would perhaps not have been used at all and the original designs would have been deemed sufficient. But the reality is that the tunnels have been

[26] Hidalgo, Klinger, Barabasi & Hausmann (2007)
[27] Hidalgo, Klinger, Barabasi, & Hausmann (2007)
[28] Algemene Rekenkamer (2003)

redesigned and safety procedures have been altered. This is not just a matter of a change in the investment costs – the costs associated the construction itself. The decision made on the basis of that particular chance event keeps resonating throughout the life cycle of the tunnel in the shape of e.g. maintenance costs and mandatory fire drills. In other, more formal terms, coupled socio-technological systems deal with non-ergodic chance events: the occurrence of chance, the results of which keep being present throughout the existence of the technology. For the researcher, the occurrence of chance provides us with a motive to develop complexity-sensitive modes of analysis. This I find particularly important in the face of certain research methods that do not just overlook the occurrence of chance but even deliberately try to remove chance events from the analysis. Turn that around! Chance is an important explanatory factor. In fact, chance may be the most stable factor in complex systems.[29]

Let's continue thinking along this path and examine the second property. If we understand that there can be variance in starting conditions and therefore in the outcomes due to path-dependence and non-ergodicity, as we have just seen in the previous example, then we need to think about the nature of the outcomes. The reality of complex systems is such that the trajectories starting under similar conditions still can bring forth different outcomes (multifinality) or, conversely, that trajectories starting under different conditions can bring forth similar outcomes (equifinality), an argument expanded upon in Gerrits & Verweij, 2013.

For example, Flyvbjerg and colleagues[30] found that the Eurotunnel, the Great Belt Link and the Øresund had very similar outcomes in terms of massive budget overruns and missed deadlines. However, a closer look reveals that safety concerns where the main cause for that in the Eurotunnel, but not in the Great Belt Link, where the budget overruns were due to environmental concerns, accidents with flooding and a devastating fire during the construction. For the

[29] There is much potential in longitudinal, complexity-informed and time-sensitive methods for the social sciences. I had a first attempt in Gerrits (2008) and Gerrits (2011) but a much better starting point here would be the work of Andrew Abbott (e.g. 2001). For a thorough application and functional model in the realm of politics and policy-making, see Spekkink (2015). An expanded argument of time-sensitive methods in combination with models from evolutionary biology is part of my forthcoming book with Peter Marks (2016).

[30] Flyvbjerg, Bruzelius & Rothengatter (2002)

Øresund link, then, it turned out that the costs of building major transport links in a densely populated Copenhagen were a magnitude higher than forecasted. In other words, what we have here are three fairly over-priced links across water (similar), yet the conditions differ massively.

The converse can also occur: similar conditions bringing about very different results. Take my home town, Rotterdam, for example. During the financial crisis, there were very little means to regenerate run-down buildings and areas so alternative solutions had to be found, at least until the next investor was found. The general idea is that the area should be opened up for temporary initiatives that can start there in a low-key, low-cost fashion with the express purpose of bring back some liveliness and economic or cultural activities to the area. The wildest dream is that such initiatives drive gentrification and cause the real estate value to go up again. The trade-off is that those initiatives need to leave on short notice should investors become interested again.

This type of temporary land use and urban improvisation is not exclusive to Rotterdam or the Netherlands. You have the same here in Germany in the shape of so-called Zwischennutzung[31] and it is also experimented with in the USA. The cases I refer to are Schieblock and Zomerhofkwartier. These two cases are at a stone's throw from each other and both feature considerable abandoned office space but no current incentive to redevelop them. Both were subjected to the same treatment of temporary use. Yet, the one project turned into a kind of office hub cum Biergarten cum coffee bar for hipsters, and slowly developed in a commercially viable place. The other one also developed but rather than evolving into something office-oriented, it appeared to attract small-scale manufacturing and artists. So here we have it: same city, same neighborhood, same situation with abandoned offices, same basic approach, but different results (and positive ones at that).

The consequences of these two aspects are clear. To the researcher, it means that any comparative analysis has account for the context in which the phenomenon occurs.[32] For the practitioners, such as urban

[31] Chang (2016)

[32] As argued elsewhere, a comparative method such as QCA has the power of uncovering the complexities of equifinality and multifinality, provided the method is used in a complexity-informed way (Gerrits, 2012; Gerrits & Verweij, 2013). A thorough

planners, project managers at a company, or politicians, it means that what works in one place may not necessarily work in another place, and that small changes can magnify in the long-term outcomes. This is less trivial than it seems once you realize how often things that work in one place are copied with the idea that it will also work elsewhere. This is not necessarily so.

The last characteristic of complexity I would like to mention here is self-organization. In formal terms, self-organization means the emergence of structure without a super-imposed design.[33] In other words: the structure emerges – literally – out of the interaction between the elements of the system. As a result, the resulting structure can't be traced back to its roots in a linear fashion. We find this property to be a persistent one, i.e. it seems to be at the basis of many complex systems. For researchers, self-organizing principles offer the keys to the inner dynamics of complex systems.

A second explanation, one that seems to resonate a lot in practice [34], is that self-organization concerns the empirical observation that people are very good at evading governmental steering attempts, i.e. they self-organize despite or because of such attempts. Consider how people walk through cities and how they create patterns of movement and conventions of how to use the public space. In that sense, I think that the Kettenbrücke does a neat job of relying on some self-organizing abilities of people to manage the different traffic flows. The reconstructed Langenstrasse, however, functions poorly despite - or even because of – the many signs and markers on the road.

6 MANIFESTATIONS OF COMPLEXITY

What we have discussed so far are some of the basic principles of complex coupled socio-technological systems. I would like also like to discuss some of the ways in which these principles become manifest in the practice of governing them. For example, if the evolution of such systems has a degree of unpredictability, then it doesn't come as a surprise that this has an impact on politics. Consider, if you will, the

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application of the method to uncover complexity in real cases can be found in Verweij (2015). Methodological guidelines can be found in Byrne & Ragin (2009)

[33] Cilliers (1998)

[34] De Bruijn & Gerrits (2016)

Fukushima disaster and the effect it had on Germany's energy policies.
Statistically speaking, the Fukushima disaster didn't change much in terms of the risks of nuclear power. Yes, it was a real disaster in the sense that factors combined in ways that were unforeseen during the design stage – the classic scenario as laid out in Perrow's normal accidents theory.[35] But no matter how severe the disaster, one can argue that the basics of nuclear power generation and its calculated risks are just the same as they have been prior to Fukushima: nuclear power plants are generally safe but there is always a small chance that things go wrong – the proverbial black swan.[36] However, for the German government, it was a clear signal that the effects of such a disaster – no matter how small the chance – would be unacceptable. In her speech to the Bundestag, Chancellor Merkel remarked that she believed the statistically small risks to be manageable. But that was before Fukushima happened. The occurrence of the disaster caused her to reconsider her stance fundamentally and to start winding down nuclear power generation in Germany.
The thing that has been haunting socio-technological systems for ever – and as has been exemplified by the speech by Mrs. Merkel – is that statistical risk assessment and risk distributions don't hold much meaning with most people. What people actually experience when dealing with complex systems is uncertainty and depending on a number of personal characteristics, they will approach that uncertainty differently. Do you believe that you are on your own and that the government is doing to you whatever it pleases? You will have a very different risk perception than people who think that all uncertainties can and should be solved in collective efforts.[37] That risk perception is an important explanatory factor for the ways in which we deal with technologies.
Earlier, I already referred to the fact that socio-technology systems are developed in networks of multiple and diverse actors.[38] This is exemplified in e.g. public-private partnerships and stakeholder involvement. Public-private partnerships, by no means a new thing,

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[35] Perrow (1984)
[36] Taleb (2007)
[37] Douglas & Wildavsky (1982)
[38] E.g. Klijn & Koppenjan (2015) for a thorough overview of literature related to public and public-private networks.

provide a way of combining public and private resources and of distributing risks between parties in establishing new, and sometimes risky, technological systems. Another aspect of this this networked society is the fact that lay people want to have a say about what is decided for them.[39]

A well-known recent example here in Germany is the societal protests against Stuttgart 21. The government of Baden-Württemberg took a heavy-handed approach towards silencing the protesters, which backfired spectacularly in the next elections. Somehow, this is a familiar pattern: legally and technically speaking everything seems to be in order, yet people don't like it much. But the strategy to decide – announce – defend simply isn't functional anymore in a highly dynamic situation. As we know by now, developing and implementing technology is not a straightforward technicality: societal actors will have their own ideas and sometimes complete disagreements and ignoring that won't make things better or easier – tempting though that may seem.

A third appearance of complexity is the different time scales at which things develop. Technology can and often will develop quicker than e.g. law. A very recent example is block chain technology, the driver behind virtual currencies such as Bitcoin. In short, blockchain technology revolves around a distributed (i.e. non-centralized) database that maintains a growing list of data entries that are unique and can't be altered after recording them. Due to its structure, it is very reliable in verifying the integrity of the data. Most people will recognize blockchain technology in the shape of Bitcoin but there are other applications too. As a so-called crypto-currency, which is what Bitcoin basically is, it has the potential to provide a stable and secure way of e.g. managing communication between banks. This could lower the transaction costs and increase the speed of transactions. But many people will also recognize Bitcoin as the de-facto standard for shady businesses on the internet. For example, the Silk Road online black market where people could order illegal drugs, utilized Bitcoins to ease anonymous transactions between sellers and buyers. As such, blockchain technology has become a public issue with strengths and weaknesses.

The working group of the European Parliament, headed by Mr. Jakob Von Weizsäcker, just tried figuring out whether this would be

[39] Edelenbos, Schie & Gerrits (2010)

something that needed to be regulated and, if so, in what ways. If you don't regulate, the technology may run out of control and cause many problems. If you do regulate right away, you may stifle innovation. Last week, the working group asked the Commission to monitor but not (yet) regulate the technology.

The debate about blockchain technology demonstrates the tensions between technological innovation and political and regulatory answers. Generally speaking, technology develops much quicker than politicians and administration can cope with. A legal change to regulate blockchain technology properly will take years to develop. The report of the working group came out last week and treats the technology as new and upcoming. But remember, the technology itself is almost a decade old by now. If it will ever come to a European legal framework, it could easily be years after the technology emerged. This is not to say that the political responses are too slow, not at all. I just want to point out that there are often considerable misfits between the pace of technological innovation and political and legal response. As Von Weizsäcker demonstrated, such delays can be beneficial in giving room for a technology to develop – hence, I like to call them 'timely misfits'. And let me stress that this gap occurs everywhere, not just in the 'high-level' politics of the European Parliament. It can also occur right here in Bamberg. As a tourist destination, how is the city going to deal with AirBnB? With Uber? The technologies are there (I know, I've rented my first apartment here through AirBnB!) so it is time for the city to start thinking about what to do. Mind, the answer could still be 'do nothing'. But an answer is required.

7 IMPLICATIONS FOR RESEARCHERS

We have now discussed some of the ways in which complexity appears in the reality of governing technological systems. The question is now what this requires from us, scientists. I wouldn't want to bother you with all kinds of technical details of the research process, such as how to solve logical remainders or whether technology users should be modeled as a box variable or auxiliary variable. I fully understand that scientists are inclined to jump on

such issues and don't underestimate how much I would like to go into the finer details of methods.[40]
But let's face it: these are not the most exciting things to discuss right now. Instead, I would like to focus on the more general approach to scientific research and the research process. If it is true – and let's assume that for the moment – that socio-technological systems are contextual and need to be studied contextually, then it is inevitable that we go out and study them in actual practice rather than from the confines of the study room. We need, in the words of David Byrne (the British sociologist, not the singer of the Talking Heads!) "[...] down and dirty empiricism"[41], grounded in the empirical word. We need to touch, smell and taste it. It is only in confrontation with reality that we start to appreciate the value of our theories and assumptions.
Theories in the social science often work by the grace of gross abstractions or simplifications. There may be some utility in that and I agree that it is actually impossible to build a theoretical framework or model that fully captures all the properties of the real world.[42] Ultimately, however, we should at least try and get a more holistic understanding of the system we are looking at. There is a real difference between accepting reduction because of practical limits and reduction as per Occam's razor.[43] So, go out, talk to people, observe them working technological systems, become embedded in the system.
We now touch upon a deeper issue, namely: what is knowledge? I'm still with Byrne, who uses the Slav word 'nauk' to indicate that all forms of organized knowledge are necessary for a better understanding of complex systems[44] – and that includes the experiential knowledge of the people working within those socio-technological systems. I think that the German word 'Wissenschaft', the art of knowing, is actually a pretty good term because it seems broader than the rather narrow term 'science'.

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[40] Among others Byrne (2002; 2004), Byrne and Ragin (2009), and Castellani and Hafferty (2009) have done a very good job of explaining what complexity-informed methods are and how they work.
[41] 2002: 42
[42] Cilliers (2002)
[43] I've expanded on this argument in Gerrits (2012)
[44] Byrne (2002)

In my view, complexity-informed science manages to make that qualitative jump from rule-based, decontextualized understanding (in itself an important step), to the experienced-based, contextual understanding of such systems; in other words: to combine cognitive understanding with intuition as a valid source of knowledge. That combination is necessary to move from data to knowledge to expertise. Intuition appears to sit uncomfortably with science but let me stress that I'm not talking about simple, irrational guess work.[45] [46] What I mean is an understanding of how complex systems work, in the terms of *knowing* how it works without having to deploy complex models or the conceptual jargon of complex systems. System theorists such as Checkland[47] and Vennix[48] have demonstrated quite well how experiential knowledge gives access to the complexity underlying socio-technological systems. Also, it doesn't mean that other approaches have been rendered invalid – not at all! All I would like point out is that we can't just limit ourselves with decontextualized research.

People familiar with researching complex systems will note that I have skipped over the most dominant approach: modeling, nowadays sometimes occurring in combination with the processing of big data. Let me say a few things about this before wrapping this theme up.

In understanding complex systems, we can deploy e.g. agent-based simulations to understand emergent properties, or use system dynamics modeling in order to understand feedback loops. The problem with modeling socio-technological systems is that it suggests that the model can be used to predict outcomes, to show that if you do this and that will be the outcome. This is a popular understanding in policy-making: if I implement policy *x*, then the outcome will be *y*, where you are free to fill in the blanks. The observation that such models have performed poorly in predicting human behavior beyond the most banal level aside, it has been show that such models suffer from, among others, confirmation bias and lack of context. That does

[45] See e.g. Byrne (2011) for an expanded argument.

[46] Flyvbjerg (2001) already mentioned the problem of the ongoing 'technocratization' in science when scientists specialize in finely-grained technical and methodological aspects but forget about real-world correspondence. This is partly inevitable because of the dynamics of today's scientific world and associated career pathways. But that should not deter us from still going outside and getting dirty!

[47] Checkland (1981)

[48] Vennix (1996)

not mean that such models are useless. On the contrary. It just means that we are asking the wrong questions from such models.
Models are primarily a means to promote thinking and communicating about complexity.[49] As Klein said: modeling forces us to become clear about the assumptions and blind spots we have regarding the system under scrutiny.[50] I find this particularly useful in the social sciences where concepts can (and often do) mean slightly different things in specific circumstances or in such instances where the researchers were not completely certain about what they were trying to convey. Models bring, even enforce, that clarity.
Computational models also have an explorative and creative function. They provide a template with which we can play around, try out some ideas and poke around in things we don't quite understand yet. And in doing so, in tapping into that creativity, I would suggest not just to stick to the serious type of modeling such as agent-based modeling and system dynamics modeling but also to play with game-like simulators. I'm certain that spending a day with the Mini Metro game or with City: Skylines will provide you with considerable appreciation and understanding of traffic allocation problems or the need for balance in generating quality of life in cities.
One example of the intersection between modeling, complexity and politics is Virtuocity. It is in use by urban planners in order to try out different designs for public space. It can even be used as a tool for participatory decision-making. As mentioned before, experts often complain that your average citizen has no real understanding of the complexity of certain tasks. In the case of Tilburg[51], the whole planning process was reversed. Citizens were invited to submit their ideas for the neighborhood. The planners and programmers then converted these ideas into virtual models in which you could walk around and see how good (or bad...) your plan was. Votes could be casted for all versions, ultimately leading to a final design that was in many ways quite bottom-up. The net result was that citizens felt that they had a real input on the shape of their town.[52]

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[49] Epstein (2008)
[50] Klein (2015)
[51] Moody (2010)
[52] Ibid.

By now, it will be clear that I favor an appreciation of complexity. Yes, it doesn't make our life easier – not directly at least – but neither does denying complexity. And what is there not to love? As Claus Carbon and colleagues, cognitive psychologists at our university, have shown, a certain degree of complexity, as expressed in novelty, ambiguity, uncertainty and conflict[53] is very much appreciated, if only because we find it interesting and because it stimulates the brain. And last but not least, the higher effort necessary to understand complexity gives us bigger rewards when we do so. The research of our colleagues concerns aesthetic complexity but I sense that there are great similarities between the "certain amount of disorientation"[54] offered by complex art and the same disorientation encountered when looking at social complexity and none of our theories seem to work as advertised. I think that the reward system also works for those that have mastered complexity as researchers or as practitioners.

Aesthetics aside, I'm actually much more concerned about the fact that denial of said complexity enlarges our veil of ignorance. If we don't understand how complexity works, we will keep developing misguided policies, projects and plans. Unfortunately, the world is littered with examples of politicians, civil servants and other actors embarking on projects and policies that turned out to be quite costly or even downright impossible because they were ignorant of the actual complexity. And as could be expected from my discussion so far, this doesn't only concern the technological complexity but also the social complexity and the interaction between them. One only needs to look at cases such as Stuttgart 21 to understand that societal dynamics not exogenous to a project, they are part of the whole system.

Don't be naïve, mind. We should understand that there are other interests to be served than the greater good. As Flyvbjerg and colleagues demonstrated: political aspirations, business interests and lying consultants can create a vicious combination under which

[53] Muth, Hesslinger & Carbon (2015)

[54] Berlyne (1971)

certain doomed projects are hatched.[55] Then again, if we are sincere in our attempts and committed to a sensible use of public funds, we better start appreciating complexity. And that is exactly the message I would like to leave you with: embrace the complexity, make it work.

9 GRATITUDE

I would like to conclude this inaugural lecture with an expression of gratitude towards this university and the Technologie Allianz Oberfranken for establishing the Chair and for selecting me as the first chair holder. Secondly, I would like to thank my colleagues at the Fachgruppe Politikwissenshaft for welcoming me here in Bamberg and for providing an intellectually stimulating environment. My gratitude goes especially to the people who are working at the Chair, who have been part of the start-up phase, or who will join the Chair later this month. You have made the transition from Rotterdam to Bamberg so much easier and the work we are doing so much more interesting. Last but definitely not least, I would like to thank my family for their support and patience, and for coming along to Bamberg.

[55] Flyvbjerg et al. (2002)

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