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Changing regimes of science and politics: comparative and transnational perspectives for a world in transition

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Against the background of previous historical changes in the configuration of science and politics, this article explores the particular new qualities of more recent changes in the relationship between these two domains. Reconfigurations of politics are outlined at the national, supranational, and international levels, while reconfigurations of science are presented with regard to four high-technologies (nuclear, information and communication, bio, and nano-technologies), hereby aiming at the interdependencies between politics and science. To this end, a regime analytical framework is developed that allows for a focus on the configuration of science and technology in society "as a whole," paying attention to comparative variation and the significance of institutions, practices, and discourses.

THESE ARE TIMES OF RAPID CHANGE. 'Globalization,' the 'information age' and the 'knowledge society' — our world is undergoing transformations that are often felt to be fundamental and new, yet at the same time seem unclear in their particular direction, quality, and outcome. While distinctive, often catchy designations can help bring our attention to something new that otherwise might not be perceived, they also may overestimate the quality of the new, or neglect that it has already been there in one way or another.

The fact that the terms pointing to 'the new' are able to gain an overwhelming presence in scientific and public discourses does not indicate that they are simply right, but that they contribute to charting these phenomena to a considerable extent. However, times of rapid or fundamental change render disputes about how best to qualify and understand them both unavoidable and necessary.

This also holds true for the role of science and politics as subjects and agents of change. For example, the term 'mode 2' has become the focus of debates about a new mode of production of scientific knowledge and the importance of its political robustness; the term 'triple helix' has efficiently communicated new arrangements among academia, business, and government as crucial for current science-based innovations (Etzkowitz and Leydesdorff, 1997; Gibbons *et al*, 1994).

In this article, I do not want to engage in these debates particularly, but rather in the more general themes of changing regimes of, and shifting boundaries between, science and politics. By doing so, the focus is extended beyond the issues relating mainly to knowledge production and innovation. As in the other debates, investigating changes in the configuration of science and politics requires further specification as to the extent to which a particularly new quality can be identified.

In section one, I present some elements of an analytical framework that aims to aid comprehension of how science and politics are part of differentiations and transformations of society, characterizing this framework in terms of regime analysis. In section

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two, I portray some aspects of the presumed 'old' configuration of science and politics, showing that changes in their relationship have taken shape for various reasons and at specific times in modern history. Next, I outline more recent changes in the configuration of science and politics that have had a mutual effect on each domain.

In section three, I show that the 'vertical' differentiation of politics at the national, supranational, and international levels affects not only social institutions, but also science. In section four, I demonstrate that the specific characteristics of particular sciences matter in respect to how they concern politics and social institutions at various levels. In these latter two sections, I focus on sciences that are closely related to the development of high-technologies. Finally, I present some conclusions and an outlook. My main argument is that the complexity and dynamics of recent regime changes require comparative and transnational perspectives.

Analytical framework

The changing relationship between science and politics can only be analyzed appropriately from the point of view of their interdependency and mutual shaping, otherwise, some form of one-sided determinism structures the investigation. This perspective has recently been put forth prominently in the contexts of "social shaping of technology" (SST) and "co-production" (Jasanoff, 2004; Sørensen and Williams, 2002).

I suggest articulating this perspective with a regime analytic framework that can be employed with regard to all domains and levels at the intersection of science and politics (an in-depth comparison between regime analysis, SST and co-productionist approaches would be worthwhile but will not be possible within the scope of this article). In general, such a framework suits the task of integrating the various scientific and technical, institutional and organizational, practical, discursive and normative dimensions of social life in ways such that conventional conceptual oppositions between structure and agency, macro and micro, stability and change can be transcended.

Regime analysis has been developed in a variety of social science research traditions, for example, with regard to international regimes, national regimes of government, regimes of supranational integration, technological regimes, innovation regimes, or intellectual property rights regimes. However, the various approaches usually operate independently of each other, that is, without taking the concepts and methodologies developed in the neighboring fields into account. This may be due, on the one hand, to the self-evident specialization of research topics and traditions and, on the other hand, to a certain ignorance that often comes with disciplinary specialization. In substantive terms, the various approaches to regime analysis are usually limited by a confinement to a particular subject area or level of analysis.

While an elaborate review of traditions of regime analysis cannot be undertaken here, it is important to note that, to date, there is no single approach that provides the necessary integrating tools. Given the numerous topics and analytic traditions that require consideration, a common terminology is needed in order to communicate better. The political science discipline of international relations — the prime context of regime analysis so far — offers a useful starting point because its notion of regime encompasses the basic sociological notion of institution, emphasizing the importance of orientations and expectations, practices and effects.

The core elements of international regimes are conceptualized as a mutually agreed set of principles and norms, rules and decision-making procedures. According to this research tradition, international regimes are established only if sovereign nation-states are willing to shift power to international agreements and organizations in both the common interest and the nation-states' own interest (Krasner, 1983).

I would like to propose a generalized notion of regime, not a general regime theory, that might contribute to a theoretical language and, ultimately, to an integral frame of analysis. Four aspects are crucial. First, such a notion refers to the basic idea that social structures are the result of human actions as well as their precondition. It is this aspect of a two-way structuring that is basic to various accounts of both sociology and science and technology studies.

Second, regimes are social structures mediated by practices that extend in time, that is, are somewhat stable, though never fixed. Third, regimes are often characterized by relations of power, which may be hierarchical, or may take other forms. Fourth, regimes can be specified by particular institutional and organizational forms and elements, such as principles and norms, rules and procedures, as they pertain to the various domains of society.

Briefly, a regime is not a given or fixed structure, but rather is more or less constantly under construction, being built and stabilized, modified and

reorganized, upheld or abolished. It is important to note that this generalized notion of regime does not presuppose the significance of a certain regime at all, which instead depends on the particular references applied. A comprehensive regime analysis provides insights into not only the empirical configuration of a given social order but also the factors that determine its cohesion, contestation, and change. However, subject-related theories may be needed in addition in order to contribute further explanations.

Since regime analysis is interested in the emergence, functioning, and transformation of social phenomena, distinguishing among the following dimensions seems essential in the context of science and politics: science and technology; political institutions and organizations; discourses; and practices. There are several reasons why these four dimensions are significant. Any given science or technology has a specific nature in and of itself, yet its particular social quality depends on the institutions and organizations that are in many ways concerned with its development and application. Discourses work as a main form of shaping social meaning. Practices are not only indispensable for anything social to happen, but can also follow a logic of their own (since practices are not simply dictated by institutions, technologies, or discourses).

In my understanding, regime analysis is opposed to deductive theoretical approaches that, for example, determine beforehand which dimension is of prime importance. Rather, it opens up room for empirical specification and variety. While there are competing theories as to how to describe and explain the relationship between science and politics — or, more generally, the 'horizontal' or 'vertical' differentiation of society — one fundamental criterion for assessing them is the extent to which they allow for empirical modification. Accordingly, comparative perspectives are of particular methodological value for mapping and comprehending the configuration of politics and science in society. Analyses can build on a variety of comparative dimensions and aspects:

- Regarding the configuration of politics: actors, institutions, practices, and meanings of politics; politics, policies, and polities as dimensions of politics; politics at the national, local, regional, supranational, and international levels; politics and its relationship to science and technology, the economy, law, culture, and the environment.
- Regarding the configuration of (techno-)sciences: actors, institutions, practices, and meanings of science and technology; science and engineering disciplines, and fields of application; high-technology related innovation, intellectual property rights, risk management, and ethics; economic, political, legal, cultural, and environmental dimensions of science and technology.

Against this background, it seems that science, technology, and society studies can profit from regime analysis. Roughly speaking, several of its subfields manifest a clear epistemological deficit that needs to be overcome in each. For example, by and large, science and technology studies need to fill the gaps in their analysis of institutions; science policy studies need to fill the gaps in their analysis of science and technology; and innovation studies need to fill the gaps in their analysis of social meaning.

While science and technology studies have mainly focused on the laboratory, they also need to acknowledge that other locations may be crucial for the generation and shaping of science and technology, for example, international organizations. While science policy studies have mainly concentrated on government institutions, they need to apprehend that science and technology are subjects of political significance, and that their particular qualities matter. While innovation studies have mainly investigated processes in and among organizations, they also need to take into account the different meanings that particular innovations have among actors and across societies.

Because of the broad empirical scope, the arguments provided in this article demonstrate the capability of regime analysis to comprehend real complexities more than demonstrating its explanatory strengths (my book on the generation, regulation, and enculturation of biotechnology provides an example of a systematic comparative analysis of interrelated societal and technological change (Barben, forthcoming)).

Post-World War II science and politics

In the debate about shifting boundaries between science and politics, this process is presented time and again as if it had been taking place only recently. While such a claim may help communicate a particular phenomenon as brand new, it obscures the layers that characterize various historical demarcations around science in society.

Along with the emergence of modern society, science and politics became interrelated (Shapin and Schaffer, 1985). While the free pursuit of science supported liberal democracy, liberal politics supported science (Ezrahi, 1990). In addition, science

Along with the emergence of modern society, science and politics became interrelated: while the free pursuit of science supported liberal democracy, liberal politics supported science; and science and engineering became part of various domains of society

and engineering became part of various domains of society. For instance, they provided the knowledge and skill basis for an increasing number of sectors of modern industry, that is, its processes, forms of organization, and products.

With the industrial revolution, science and engineering had themselves become integral to the enterprise of industrial capitalism, transforming the modes of production, together with the infrastructures of society (Freeman and Soete, 1997; Landes, 1969; Noble, 1977). Mechanical and chemical engineering and electrical power systems are prominent examples. Governments developed more or less elaborate frameworks for funding research and for implementing science and technology policies. This led, among other things, to the founding of new institutions such as institutes of technology and polytechnics, the purpose of which was to carry out research and development (R&D) and provide an appropriately skilled workforce.

Furthermore, science and engineering became integrated into the procedures for regulating technological risks by providing measures and means for assessing them. An early example is the risks associated with the steam engine. However, connections among science, politics and industry that had emerged particularly in the 18th and 19th centuries did not undermine the conventional notion of separate domains of human activity, their norms and values.

According to the idea of a clear boundary, it was considered the obligation of scientists and engineers to pursue true knowledge and efficient technologies, while the application of science and technology was seen as the responsibility of government and industry. This distribution of obligations and responsibilities found its expression in institutionalized norms and codes of conduct. They were characteristic for both civil and military affairs: scientists and engineers would seek discoveries and develop new products and processes but reject being held accountable for the consequences of their use; and they would create new weapons but deny any responsibility for their application.

This regime configuration was challenged in the aftermath of World War II, at first only with regard to the military involvement of science. The engagement of prominent physicists in the Nazi efforts to develop an atomic bomb (and other weapons), and the actual launch by the Americans of two atomic bombs on Japanese cities in August 1945, led to fundamental questions about the role of physicists. Physicians also came into question because of their involvement in Nazi medical experiments, which inspired the reformulation of basic and worldwide accepted medical ethics in the Nuremberg Code of 1947 that followed the war-crimes trials. In the face of these horrible events, scientists themselves started debating their power and responsibilities (Annas and Grodin, 1992; Schweber, 2000).

The post-World War II order established stability in the world in an unprecedented way. A basic condition for this was the balance of power between the two competing superpowers — the USA and the Soviet Union — which was fortified by a huge arsenal of nuclear weapons on both sides of the Cold War division. By virtue of its potential for mutual destruction, the cumulated weaponry encouraged the peaceful behavior of the two dominant powers.

This situation also ultimately motivated both superpowers to enter talks about limiting the nuclear arms race. This context of international politics was the first in which a concept of international regime was developed, which included debates about new forms of power and the loss of national sovereignty, respectively (see, among many others, Krasner, 1983).

In the decades after World War II, economic and societal prosperity prevailed in the most advanced countries of the West to a previously unknown extent, enabling welfare-state institutions to flourish. Part of the expansion of government activities was the significant support of science and technology through new policy frameworks, agencies, and high levels of funding. The vision of a 'social contract for science' became influential not only in the USA (usually associated with Bush, 1945).

According to this social contract, governments should continue to support scientific and technological research, by granting substantial freedom to basic research that was to be assessed by peer review and performed with integrity and high productivity, leading to discoveries, industrial innovations and other benefits. Of course, science and technology policies took different forms in the various countries, also as regards the importance of military R&D and the linkage with industrial R&D.

The balance of power between the USA and the Soviet Union limited the range of options of societal and political change for both the main allied countries and the newly constituted 'third world' countries. The developing countries had successfully become independent through decolonization in the 1960s, a major process of political and social change in the 20th century. These countries would later become subject to modernization regimes, with science and technology considered fundamental for economic growth. Such regimes were usually shaped not only by national actors and forms of government, but also by one of the superpowers, or by international organizations (Haggard and Kaufmann, 1992; Sørensen, 1991).

At the international level, the stability of the world economy was supported by new international organizations, in particular the International Monetary Fund (IMF) and the World Bank — two core institutions of the international economic regime established in Bretton Woods (Schild, 1995). The founding of these organizations was an answer to the economic crises of the 1920s and 1930s on the one hand, and to the needs of reconstruction and development after 1945 (and after decolonization) on the other.

The changes hereby represented were comprehended as "embedded liberalism," which appropriately characterizes the post-World War II order (Ruggie, 1983). The United Nations provided a new framework for efforts to master challenges to the international community with respect to, among other things, peace and security, development, human rights, health and the environment, and cultural exchange. These areas of international politics also became the subjects of international regime analysis.

The rapid and sustained industrial expansion and economic growth after World War II finally prepared the ground for challenges to the boundaries drawn around science in civil affairs. The new social movements that emerged in many countries between the mid-60s and mid-70s criticized, in addition to the continuing importance of military R&D, the social, and in particular the environmental and health, ramifications of industrial production as often gravely dangerous but neglected in public until their detrimental effects had already had a significant impact.

The positive reception of such criticisms by various social groups led to a higher awareness of potentially unwanted consequences of industrial production, and/or the use of its products, on the part of those actors concerned with technology development in engineering, industry, and government. Thus also scientists and engineers in industrial R&D were forced or encouraged to take into account an ever broader spectrum of concerns and responsibilities in their work, among them various risk, ethics and privacy concerns. In the end, fundamental changes in the relationship between science, politics, and industry occurred, which led to increased accountability concerning issues that were previously most often considered outside the domain of scientists and engineers (Lash *et al*, 1996; Weingart, 2001).

To sum up this brief sketch, I would like to draw three conclusions. First, the development of modern industry led to closer ties between science and technology, that is, starting with physics and chemistry in the 19th century, to science-based technology and economic sectors.

Second, the expansion of political functions, in particular in the form of (welfare) state intervention and international institutions mainly after World War II, brought formalized or authoritative scientific knowledge (in particular from economics, law, and political science) closer to politics. Thus the institutions of national and international politics were often associated with new bodies of scientific expertise that were to provide special knowledge for designing, advising, or legitimizing their policies.

Third, both the engagement of scientists and engineers in bellicose projects of spectacular destruction, particularly in chemical warfare in World War I and, 30 years later, in nuclear warfare, and the environmental and health risks posed by industrial production and its products, generated claims for new forms of (self-)regulation and accountability.

Against this historical background of various layers of connections among science and technology, politics and industry, I will review more recent changes in the configuration of science and politics.

Recent changes in configuration of politics

International level

A historical event often presented as a crucial starting point for recent international transformations is the suspension of the Bretton Woods regime in 1973 (Stubbs and Underhill, 2000). Increased international trade and a number of financial crises put pressure on international currency relations, so that they became unmanageable under the rules that had been successful for almost 30 years. In consequence, the fixation of both the US dollar to the gold standard and the value of the world currencies to each other were given up.

From then on, the currency relations would be left to the markets and not be supervised and supported by the IMF. Thus the global financial markets gained power over national governments in the sense that a widespread international disregard for a government's economic policies could lead to the dramatic fall in value of a national currency. An example is the drop of the French franc under the Socialist–Communist Government of President Mitterrand in the early 1980s, which provoked a policy U-turn in France.

The IMF's main role since the 1970s and 1980s has become to assist countries in financial crises, particularly through the so-called structural adjustment programs. To receive loans for overcoming an acute financial crisis, governments were forced to take steps, such as lifting trade barriers, suspending price controls, and reducing public spending and the budget deficit. The principles and norms steadily promoted by the IMF (and the World Bank) became later known as the "Washington Consensus" (Stiglitz, 1998; Williamson, 1990; 2000).

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and programs, which is itself an indicator of fundamental political change in the post-World War II era. This era ended in the mid-1980s with the collapse of the authoritarian state-socialist regimes previously integrated by the Soviet Union.

Economic liberalization became further strengthened by the founding of the World Trade Organization (WTO) in 1995 that succeeded the General Agreement on Tariffs and Trade of 1948 (GATT). Both GATT and WTO were based on the same principles and norms of promoting free trade, but the WTO was granted more competence with respect to the realms in which free trade principles are valid and to the rules and procedures by which these principles can be enforced (Hoekman and Kostecki, 1995).

Three agreements constituted the wide-reaching importance of the WTO regime: the updated GATT; the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS); and the General Agreement on Trade in Services (GATS). While GATT concerns the free trade in goods, the GATS requires the liberalization of the service sector, and the TRIPS agreement demands an extensive acknowledgment of intellectual property rights, among them patents to protect inventions. All member countries, and any wanting to become a member, are obliged to legally acknowledge the WTO agreements. In cases of conflict, the WTO possesses powerful institutional means for settling disputes and enforcing sanctions.

The consensus underlying the politics of globalization during the 1990s assumed that the liberalization of world trade, which includes the deregulation and privatization of economic affairs within the nation state, would create more beneficial effects than any form of so-called protective government policy. In other words, the fundamentally liberal idea proclaimed that granting power to the free markets was in the best interest of economic, technological and social development in both advanced industrial and developing countries (for competing perspectives, see Bhagwati, 2002; Stiglitz, 2002).

As long as the principles of the Washington Consensus were not fundamentally challenged in public, they were simply considered 'good economic practice' and state-of-the-art economics. This changed after the violent protests at the WTO ministerial conference in Seattle in 1999. After this event, and similar ones that would follow, fundamental criticisms of the predominant economic policies of globalization voiced by some developing countries, transnational NGOs (non-governmental organizations), and non-mainstream economists received much broader attention. It also became clear that the world market was structured by power asymmetries, since important sectors, such as agriculture, had been politically exempt from liberalization in order to maintain massive subsidies in the USA and the European Union (EU) (Cavanagh and Mander, 2004; MacEwan, 1999; Tabb, 2001).

In addition to the international economic regimes, international environmental regimes and international technology regimes have gained importance during the past decades not only as such, but also with regard to science. International environmental regimes regulate, among other things, the protection and use of particular territories, natural resources or species such as the Arctic, the ozone layer or whales (Lansford *et al*, 2002). Science often plays an important role in the decision-making process of whether and how to implement an internationally binding agreement. For example, science is to provide the knowledge about the characteristics and causes of environmental problems as well as, if possible, sound solutions.

The problems of global climate and environmental change, in particular, have contributed to the establishment of international research consortia and research programs, leading to new relationships between science and politics in international organizations and transnational cooperation. Examples are the Intergovernmental Panel on Climate Change and the World Climate Research Program initiated by the International Council of Scientific Unions (ICSU), the World Meteorological Organization, and the Intergovernmental Oceanographic Commission; the ICSU's International Geosphere-Biosphere Program; and the Human Dimensions of Global Environmental Change Program initiated by the International Social Science Council (Elzinga, 1995).

International technology regimes concern particularly security and safety issues related to the development or application of technologies such as military uses of nuclear, chemical and biological technologies on the one hand, and risks related to the trans-boundary movement of products or technologies on the other. Economic regimes, for example the WTO, may contain regulations on the environment and on technologies. At the same time, environmental and technology regimes are of economic importance by setting limiting or enabling conditions for economic activities. Similar to the configuration of politics at the national level, international regimes have to balance the highly valued norms of economic and scientific freedom with the protection of health and the environment across borders.

National level

Liberalization policies and environmental or technology policies at the international level were promoted by national governments, who also constitute the members of internationally binding agreements. Often domestic policy priorities shape national agendas in international politics, or have transnational effects on other governments. For example, after the election victories of the Conservative Governments presided over by Margaret Thatcher in the UK and Ronald Reagan in the USA in 1979 and 1980, 'free market' policies experienced a general upturn (King and Wood, 1999).

On the other hand, priorities set in international politics can help governments change, or circumvent, national policy agendas. So governments often referred to 'globalization' as a process that leaves no alternatives for national policies other than adaptation to global economic developments. In this discourse, national policies are basically seen as forced to comply with the 'free market' goals of deregulation and privatization.

It has been a long-standing dispute in the public and the social sciences as to the extent to which national governments are still able to exert sovereign power as set out in their constitutions. The two extreme positions have been that national governments have completely lost their ability to design policies according to a deliberate democratic will, and that they have not lost this ability at all. The policy areas considered particularly sensitive in this regard are those that concern economic competitiveness (Cerny, 1997; Evans, 1998; Rhodes, 1998; Scharpf, 1998). Since the performance of economic sectors and companies is affected by, among other things, conditions set by national regulatory frameworks and national infrastructures, business interest organizations and companies tend to put pressure on governments to achieve more favorable conditions.

It had always been important to governments of capitalist democracies to support the 'national industry,' not least to improve the prospects of electoral success thanks to a prospering economy. Recently the tasks of national economic growth and employment have changed significantly, though remaining as important as ever. A more liberal international framework and increasing transnational economic activities, such as foreign investments by transnational companies, brought about a power shift on behalf of these companies against the national governments (Crotty *et al*, 1998). Since transnational companies can always threaten to dislocate part of their activities or to leave a country completely, governments are pressured to improve the conditions for those companies that constitute the most powerful economic actors.

Because of the increased significance of international competition in the global economy, governments and a variety of other actors stress the importance of various policy fields for improving or sustaining competitiveness (Cerny, 2000; Gamble and Wright, 2004; Mudambi, 2003). Areas in which governments started competing against each other more and more are taxation, labor market, welfare, infrastructure, environment, and science and technology policies. However, policies in these fields have not been subject to transnational competition completely, and, if they were subject to competition, a spectrum of diverging policy options remained at the disposition of national (and regional) governments.

In other words, even when deregulation, flexibilization, or privatization were the guiding principles in policies of promoting competitiveness, they could be implemented in different ways, and be complemented by additional principles, such as balancing social and economic disparities. Accordingly, the Washington Consensus was interpreted in quite different ways in individual countries because of particular political traditions, cultures, and conflicts. In addition, the various policy fields have provided battlegrounds for competing knowledge claims by the government and its opposition, administration officials across the different departments, interest groups, think tanks, and civil society organizations.

Regime analyses of the relationship between politics and the economy at the national level and of the nexus between the national and international levels suggest that 'liberal market' and 'corporatist market' regimes constitute different varieties of capitalism, which still embrace significant variation among the individual countries (Crouch and Streeck, 1997; Hall and Soskice, 2001; Hollingsworth and Boyer, 1997; Kitschelt *et al*, 1999). While liberal market regimes have, all in all, proven better able to adapt to both the persistent crisis that became manifest in the 1970s and the challenges of economic liberalization in the 1990s, this does not imply that they have performed better in all economic and technological sectors, or that their public services and infrastructures are in better shape.

Although these analyses pay attention to the particular modes of innovation, they hardly reflect on the specific forms and contents of science and technology. Generally, fundamental economic and societal crises create challenges that can be met better by some economic and political regimes than by others. While each historical era provides or privileges a range of options for societal organization, each national regime is shaped by national institutions and traditions that decide on opportunities and limitations to solving particular problems (Esping-Andersen, 1990; Gourevitch, 1986; Jessop, 1995).

As regards science and technology policies in particular, governments have developed and combined a broad range of policy instruments to meet the overall goals. Not all policy instruments were new, but they were often given a particular emphasis, hence contributing to regime change. For example, governments have continued to provide funding for basic research, but they were increasingly looking out for those areas that might be most up-and-coming and likely to have a broad economic impact. Since decisions about which areas should be granted funding have been characterized by high degrees of uncertainty, governments would not only rely on the advice of science and engineering experts, but also take into account the decisions made by the governments of the main competitors.

The most significant changes have taken shape since the 1980s with respect to new modes of linking academic research to commercialization. To this end, institutional mechanisms were created that would allow, encourage, or oblige researchers to engage in private commercial ventures or in market-oriented

Since the 1980s, mechanisms have been created that allow, encourage, or oblige researchers to engage in private commercial ventures or in market-oriented S&T transfer: governments have improved conditions for start-up companies or innovative small and medium-sized businesses

science and technology transfer. In addition, governments worked on improving the conditions for start-up companies or innovative small and medium-sized businesses. Generally, governments reorganized, and partly extended, their efforts in science and technology policy, although to varying degrees.

For example, in the USA, the Bayh-Dole Act of 1980 (Public Law 69-517), the Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480), the Technology Transfer Commercialization Act of 1980 (Public Law 106-404), the Trademark Clarification Act of 1984 (Public Law 98-620), the Federal Technology Transfer Act of 1986 (Public Law 99-502), the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418), and the National Competitiveness and Technology Transfer Act of 1989 (Public Law 101-189) were strategically related measures — some of them landmark legislations — that were to set standards for systematic commercially-oriented science and technology policies in other countries. As a consequence, traditional institutional boundaries between the private and the public realms were shifted on behalf of the former, for example, by enabling and promoting private exploitation of publicly funded research through patent rights and other means. This, in turn, led to a variety of new conflicts concerning the conduct of research or scientific communication.

The emergence of "competitiveness R&D policy coalitions" (Slaughter and Rhoades, 1996) was accompanied in several countries by political demands to implement new forms of evaluating research, binding these evaluations to decisions about the allocation of institutional funds. Thus the autonomy of the scientific community regarding the definition of research agendas and quality control has been questioned on behalf of the external usefulness and accountability of research projects. While such priorities have already been more common in the private sector, their implementation in the public sector contributed to what could be perceived as an institutional crisis of the university.

Conversely, universities, or, more general, all academic research institutions, have gained a growing importance in economic innovation. This is also reflected in a shift in innovation studies. While the national innovation systems approach mainly focused on the role of companies and innovation-related government policies, the triple helix approach expanded its focus to the role of universities and networks among academia, industry, and government (Etzkowitz and Leydesdorff, 1997; Nelson, 1993).

Supranational level

Within the last 50 years, the process of European integration has brought fundamental changes for all member countries of the EU, establishing an increasingly complex supranational regime. Starting with the Treaty establishing the European Coal and Steel Community in 1951, the European Community has been functionally expanded to the European Economic Community (EEC) and the European Atomic Community (Euratom) in 1957, to the Merger Treaty establishing a single Council, a single Commission, and a single operative budget in 1965, to the Single European Act as the first major reform of the Treaties in 1986, to the Maastricht Treaty in 1992 that institutionalized cooperation in foreign policy, defense, police and justice under one umbrella, the EU. This treaty also created the economic and monetary union, put in place new Community policies in education and culture, and increased the powers of the European Parliament.

Since the mid-1980s, the goal of establishing the common market has served as the prime task for modernizing the European Community, by eliminating internal barriers for the transfer of capital, goods, and work forces. Although the common market has served as a driving force in the process of European integration by enhancing overall economic competitiveness, this process cannot be reduced to a mere free trade project. A number of policy areas the EU has increasingly engaged in, including environmental, social and employment policies, make it clear that the EU is much more than a common market regime.

The rising number of policy areas, together with the strengthening of Community institutions as agreed in the Treaties of Amsterdam and Nice in 1997 and 2001, are indicative of a fundamental supranational transformation and reorganization of European politics. In consequence, government in the EU has become a complex multi-level configuration at the national and supranational levels (Crouch, 2000; Grande and Jachtenfuchs, 2000).

Science and technology policy already played a role in the treaties of the 1950s, with regard to the old industries of coal and steel and the new industry of nuclear energy, although it was not a designated area of Community politics in the EEC treaty. The goal of the common market, in particular, brought up the idea of a European technological community. Since the late 1980s and early 1990s, research and technology policy became part of legal agreements that were mainly intended to strengthen the scientific

and technological basis of European industry (Peterson and Sharp, 1998; Sharp, 1985).

Research Framework Programmes have been of major importance for outlining and pursuing R&D priorities together with a broad variety of instruments. The Sixth Framework Programme (2002–2006) is oriented towards the creation of a European Research Area. In addition to funding research and technology across Europe, Community activities are also involved in regulating environmental and health risks, patenting, and ethical issues, and, more recently, in coordinating higher-education policies. Thus science and technology policy became an integral part of the multi-level configuration of politics in the EU (Dresner and Gilbert, 2001).

In sum, I would like to draw three conclusions here. First, politics has become increasingly differentiated among the national, international, and supranational levels (and, not to forget, the regional and local levels) such that a complex multi-level configuration of politics has emerged. Regime analysis is thus required, and able, to account for this fundamental change. At the same time, the design, coordination, and implementation of policies at all levels has been confronted with a broad variety of problems and conflicts, such as the legitimacy of political actors and the effectiveness of policies.

Second, within this configuration, international regimes, and, especially as regards Europe, supranational regimes, have gained importance over the nation states. Because of the significance of free market oriented international economic regimes, there has been a power shift to large transnational companies, and increasing transnational competition among nation states in various policy fields, posing challenges to the foundations of democratic politics (Sakamoto, 1994).

However, the market-oriented transformations since the 1970s, including the dynamics of globalization since the 1990s, have not left national governments without any room for maneuver, although divergent options have remained available in the different policy areas only to a greater or lesser extent. In addition, new arenas of political mobilization have been created, for example, by transnational NGOs. Nevertheless, the nation state is still the prime frame of reference for shaping political, social, and cultural identities and actions.

Third, changing regimes of politics within the evolving global economy have rendered science and technology more important for enhancing competitiveness. There has also been an increasing demand for science and technology to assess a broad variety of problems and to create solutions in the policy areas concerned, thus rendering the contexts of application of science and technology more prominent and, at times, leading to new international research consortia and programs (especially as regards global environmental and health problems).

The changes toward 'competitiveness' in the relationships among science, politics, and the economy, as well as new demands for accountability, led to debates about a redefinition or retirement of the social contract for science (Guston, 2000). The increasing importance of competitiveness is also reflected in reports and recommendations by the Organization for Economic Cooperation and Development (OECD), which has been influential as an international advisory body to governments in many policy fields (see, for example, OECD, 2005).

Recent changes in configuration of science

The second half of the 20th century was characterized by an increasing number and dynamic of high-technology developments. As political change has influenced developments in science and technology, these developments have had an influence on the configuration of politics and policies. Some examples follow.

Nuclear technology

At the end of World War II, nuclear technology was not only proven to be an immensely destructive technology for military purposes but was soon also considered a technology able to produce unlimited amounts of cheap and clean energy. Thus it would fulfill the constantly growing demand for electrical power in industry and, with a whole new set of appliances becoming available, in households.

However, the development of nuclear energy turned out to be much more expensive than initially expected. It also demanded the active support and coordination of the state, without which nuclear energy would not have been developed, although, in later stages, the development of nuclear energy took different forms in different countries with respect to the relationships between state and industry (Campbell 1988).

In addition to government funding, government agencies faced a variety of possibly serious hazards that required new institutional efforts with regard to safety and risk regulation. Safety and risk issues were in particular related to the construction of nuclear power plants, the operating procedures and the training of the work force, the nuclear fuel reprocessing, and the final storage of nuclear waste that would remain active in the environment for a very long time because of the particular half-time of nuclear material (OTA, 1984b).

The basic characteristics of nuclear energy, including its state-centered structure, made nuclear energy a prominent subject of long-lasting conflicts in many countries, and thus part of a regime that was contested not only as to how to design and regulate, but also whether to sustain and further develop, nuclear energy. While nation-state agencies have mainly been responsible for regulating nuclear energy, safety and risk management also required establishing an international regime. Because of the risks inherent in

nuclear technology, safety standards for nuclear power plants had to be set and monitored.

However, the worst-case accident of Chernobyl in 1986 could not be prevented, and its consequences would cross many national borders and affect many generations to come. Since nuclear material and technology could be used for military purposes, it was also an important, and internationally widely acknowledged, goal to prevent more and more nation states from achieving the capacity to produce nuclear weapons.

The International Atomic Energy Agency, established in 1957 as part of the United Nations, serves as the world's most important intergovernmental organization in nuclear technology. After the collapse of the Soviet regime in the late 1980s, nuclear proliferation became an even more dangerous issue. Now not only nation states, but also criminal or terrorist groups could potentially try to sell or acquire nuclear material, making the monitoring and controlling of such unwanted activities much more difficult than before, if that is possible.

Information and communication technology

Microelectronics brought about a revolution in information and communication technologies. Though started already in the 1940s, it came to full fruition in the 1980s. Since then, hardly any area of modern life has been left untouched by microelectronics. It thus became a model for a most powerful key technology with the potential to become part of almost all economic sectors, and, by virtue of innovation, to open up and gain immense markets (Brock, 2003; OTA, 1985).

As a result of the overall decentralized, yet increasingly international, structure of information and communication technologies, the political challenges associated with them not only depend on the areas of application and modes of use, but also involve a number of cross-cutting issues linked with reorganizations of power (Rosenau and Singh, 2002). For instance, the widespread electronic storage and use of personal information brings up privacy issues, with regard to both corporate and government demand for, and use of, sensitive data. The extensive production and use of electronic devices such as microchips, computer monitors, or mobile phones may cause safety problems for human health in one way or another. The internet is not only subject to competing governance claims, it is also a medium that changes the ways in which people connect to the world as news readers, students, political activists, or criminals.

In all these cases it has been debated as to whether, and how, there was a need to shape regime structures that complement those that emerged spontaneously — an issue that has found different responses in different national and international contexts. An issue related to the particular 'immaterial' quality of information technology has gained overall prominence and become a subject of controversy and powerful regime building, namely intellectual property rights.

Since a great number of information and communication technology products can easily be copied and multiplied, inventors and innovators have feared the infringement of property rights. Industrial property rights, in particular, patenting, had been created as an institutional form of protecting private inventions in the course of the industrial revolution in the mid and late 19th and early 20th centuries. At the same time, patenting required the publication of inventions so as to expose them to public scrutiny, and to make them available to further innovative activities by actors other than the initial inventors. It was the widespread diffusion of electronic information technology that inspired the conceptual extension of industrial property rights to intellectual property rights (Boyle, 1996; Halbert, 1999).

Because information and communication technology had become a driving force of the rapidly globalizing economy and a significant element of everyday life around the world, the actual acknowledgment and protection of intellectual property rights became a crucial issue to those producing computer software, music or films, among other things. It is the agreement on TRIPS of the WTO that pays particular attention to this technological change in the international economy. The regime constituted by the TRIPS agreement provides powerful means for demanding from nation states that they respect, and enforce, intellectual property rights (Matthews, 2002; TRIPS, 1994).

For example, as a precondition of membership in the WTO, China was required to acknowledge and protect intellectual property rights officially both in international trade and at home. The underlying reason for this kind of international conflict is the disadvantaged position of developing and threshold countries in the global economy. While these countries often have strong aspirations to catch up and close technological (and thus economic) gaps, they usually lack the technological and financial capabilities to either produce or acquire high-technology in a legal manner.

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As the global economy is characterized by fundamental disparities of wealth and power, the issue of intellectual property rights also has an ethical dimension. This applies for the issue of the 'digital divide' between the global North and South (which goes beyond problems of intellectual property rights, and also concerns the people of developed countries; see Warschauer, 2003) and, more specifically, for health-care related pharmaceutical industry issues (see below).

Intellectual property protection has also become a tense legal issue in the advanced industrial countries (including the EU). The internet, for example, enabled people to exchange or download electronic information easily. Since this affects the interests of the software, music, and film industries, these branches lobbied for a strict enforcement of intellectual property rights against what they consider illegitimate commercial and private uses.

This issue has been controversial for quite some time not least because the position taken by industry denied a right that had been previously taken for granted, that is, to make copies for non-commercial private use. However, the problem of proprietary information obstructing their use and further development encouraged attempts to provide open source platforms as an alternative.

Biotechnology

With the advent of genetic engineering in the early 1970s, biotechnology started emerging as a new powerful key technology of the future. Based on the scientific breakthroughs and findings of a broad variety of disciplines, in particular, molecular biology, which revolutionized both the scientific and popular understanding of life, biotechnology was to open up new horizons of technological innovation in a broad variety of economic sectors (Bull *et al*, 1982; OTA, 1984a).

While biotechnology was established as a new integrative field that extends our understanding of life and the potential to manipulate it according to an unlimited variety of purposes, its development took place in an uneven manner and speed because of its nature as a cross-sectoral technology. Accordingly, the interests of public and private actors and the given or prospected markets have differed significantly in medicine, agriculture and foods, environment, energy and raw materials production, among others.

Although the multiple scientific and engineering disciplines that constitute biotechnology have contributed to an ever more sophisticated understanding of the unity of life, transfers of knowledge or methods among the different sectors often faced more difficulties than initially expected, as did the successful development of new products in general. In addition to intra-technological differences, those between countries played a significant role in the development of biotechnology. Certain countries, in particular the USA and Great Britain, were better able to build the scientific and technological basis for biotechnology and to commercialize it than others, for example, Germany.

Various factors contributed to this differentiation; however, they can mainly be attributed to the diverging performance of national innovation regimes (Casper, 1999; Jasanoff, 1985). Biotechnology had become a prime example for the crucial importance of close collaboration between academic research and corporate actors, in particular venture capital, start-up and transnational companies (Kenney, 1986). This characteristic requirement of innovation in biotechnology could be met better by countries whose political, institutional, and cultural traditions belonged to the liberal, as opposed to the corporatist, type of capitalist regime.

The notion of national innovation regime usually refers to the capability of academic organizations, companies, and government agencies of a country to generate innovations. Since the successful implementation and appropriation of innovations also depends on further societal factors, innovation regimes intersect with the institutions and practices regarding risk management, patenting, ethics, and acceptance politics. All these areas have contributed to the social configuration of biotechnology at the national level, which is why I suggest extending the notion of innovation regime to include those areas.

As a result of the often broad resonance of biotechnology issues in society, claims for new forms of social accountability and consultation in science and technology affairs were raised again and again. This led to the programmatic integration of research on ethical, legal, and social issues (ELSI) into the large-scale Human Genome Project first in the USA and later elsewhere. Actors related to new social movements or to a variety of NGOs successfully argued in several countries for the implementation of participatory technology assessment procedures such as consensus conferences or scenario workshops (Abels and Bora, 2004; Joss and Durant, 1995).

The issue areas of risk management, patenting, and ethics have also been important at the supranational and international levels (Barben and Abels, 2000). For example, after risk management had been an intensely debated issue at the national and local levels, it also became part of supranational and international arenas. Safety and risk management have been integrated into the regulatory regimes of the EU, dealing with the same issues as at the national level, but often in conflict with different positions among the member states (Levidow *et al*, 1996).

At the international level, risk management of biotechnology attained particular consideration with the Cartagena Protocol on Biosafety that had been negotiated as a multilateral environmental agreement under the Convention of Biological Diversity. Since the Biosafety Protocol pays particular attention to the precautionary principle with reference to environmental and health risks, there is some tension with

the WTO agreements, in particular the Agreement on the Application of Sanitary and Phytosanitary Measures and the Agreement on Technical Barriers to Trade, which state the clear priority of free trade and thus acknowledge risk issues only to the extent of definitive scientific proof. The respective importance of the competing regulatory regimes will depend on how future trade conflicts are resolved.

Within the EU, biological patenting has proved a deeply contested issue both at the supranational level and between the European and the member-state levels. While some areas of biotechnology had become subject to industrial property protection regimes at the international level, in accordance with the industrial development of microbiology or plant breeding earlier in the 20th century, the agreement on TRIPS enhanced the intellectual property protection in all areas of biotechnology. A strategic conflict has concerned competing regime principles in agriculture regarding patent vs plant variety protection — an alternative that implies diverging degrees of commercialization and distribution of power between transnational seed companies and farmers.

Despite the overall high importance of intellectual property rights for the WTO, expressing hereby the dominant position of the most advanced countries and industries, the agreement on TRIPS also embodies significant compromises negotiated among the fundamentally unequal WTO members. Dramatic health crises, such as that caused by AIDS in several countries, helped developing and threshold countries such as Brazil in their struggle to obtain exemptions from patent right protection at least with respect to the production and use of generic drugs (TRIPS: Article 31 (b)).

However, such compromises help legitimate both the WTO and intellectual property rights. In all cases of conflict — biological safety, intellectual property rights for pharmaceuticals, plants, animals, and genetic information — transnational NGOs have played an important role. Ethics regimes, unlike the other areas, have remained rather weakly institutionalized.

The Convention on Human Rights and Biomedicine of the Council of Europe, which comprises more member states than the EU, has been widely considered very problematic, with the consequence that several countries, for example Germany, have been unwilling to sign it (COE, 1997). The Declaration on the Human Genome and Human Rights of UNESCO is not legally binding at all, yet it provides a basis for normative accountability (UNESCO, 1997). Finally, attempts within the UN to reach agreement on an international ban against human cloning failed in 2005, mainly because of national differences about how to deal with the so-called therapeutic or research cloning.

Nanotechnology

Nanotechnology is still in a very early stage of its development. The term generally refers to technologies at the nanometer scale (one nanometer equals one millionth of a millimeter), which implies fundamentally new prospects in the exploration and exploitation of matter. The potentials of nanotechnology apply to a broad range of scientific and technological fields, which, through the advent of nanotechnology, will themselves become reconceptualized and reorganized, at least to some extent.

Nanotechnology, too, is a cross-sectoral technology relevant for materials science, manufacturing, energy production and storage, medicine, food, water and the environment, and the military, among others. Nanotechnology is expected to be particularly powerful because it will be accompanied by what are called 'converging technologies.' Thus nanotechnology is not just the latest, in this case physical and chemical high-technology development, but also is becoming increasingly connected to biotechnology, information technology, and cognitive science.

Accordingly, nanotechnology has faced, or will face, issues relating to health and environmental safety, security and privacy, intellectual property rights, and ethics (National Science Foundation, 2001). However, it is too early to tell what kinds of regime will actually emerge, or how existing regimes will be reorganized.

To summarize this section on recent developments, first, the major developments of science and technology within the last few decades have led to ever closer connections between them, widely establishing the phenomenon of techno-sciences and science-based industries that affect numerous societal domains. The emergence and embedding of complex technologies in economic sectors, and in society, builds the context for technological regime analysis, that is, in slightly different terms, the analysis of the interdependency between the social shaping of technology and the technological shaping of society (Freeman, 1993; Williams and Edge, 1996). This suggests extending the predominantly economic framing in the analysis of innovation regimes towards the configuration of technologies in societies.

Second, those high technologies that emerged, or experienced a breakthrough, in the 1970s and after,

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have been increasingly generated within regimes of innovation that incorporated extended or substantially new structures and practices oriented towards commercial applications, indicating a new relationship between public and private. This was particularly suited to those technologies that, unlike nuclear energy, were of a decentralized structure.

Transnational dynamics have not only been characteristic for competitive technology developments, but also for the controversies on environmental and health risks, intellectual property rights, and ethics. Not least important among the transnational repercussions have been demands for the increased accountability of the science and engineering, and business and science policy communities, together with claims for institutional, social and technological change towards sustainable development.

Third, the particular qualities of the sciences and technologies concerned have brought about a broad spectrum of challenges to social institutions and politics (including policy fields and at times even polities) at various levels. This has often led to institutional, political or, more generally, societal change.

Because of the perceived strategic importance of science and technology for economic competitiveness in the transformation process towards 'knowledge societies,' it is no surprise that universities have become increasingly subject to, at times, far-reaching organizational change (Slaughter and Rhoades, 2004). Consequently, universities are not only asked to pay more attention to marketable research, but also to become themselves more efficient organizations or to reorganize the traditional disciplinary structures into more problem-oriented research and teaching networks.

Conclusions and outlook

The overview presented should not only illustrate recent regime changes of science and politics, but also provide us with some insights about the modes and factors of change in both domains and in their mutual relationship. Because of the broad scope of this outline, it has not been possible to flesh out in more detail how the regimes have been configured in practice in terms of the various social dimensions, domains, and levels. The intention here was to demonstrate that a generalized regime analytical framework provides a range of orientations and differentiations that help us to understand the various connections between regimes of politics and those of science in both theoretical and empirical regard.

Against this background, existing approaches to regime analysis appear to have been confined to a particular dimension, domain, or level of sociality. For example, institutionalist analysis has often lacked an interest in social meaning, while discourse analysis has tended to neglect the significance of institutions. Innovation regime analysis has mainly paid attention to those organizational concerns that are more or less directly affecting economic competitiveness, without taking into account those issues that concern innovation via complex social mediations. International regime analysis has been shaped by typical institutional and normative concerns of international relations, usually without connecting to other levels of politics.

In general terms, a regime analytical framework suggests analyzing configurations of science and technology in society, thus also approaching the complex interdependency of social and technological change. Boundaries drawn around science then no longer appear to be essentially fixed, but to be shifting and hybridizing time and again with one or more societal domains (concerns that, in particular, analyses of co-production share).

In addition to its integrative capacities, such a framework also provides tools for detailed studies of how social phenomena are generated and established, presented and contested, regulated and appropriated. In the end, a comprehensive picture can be obtained, elucidating the structures and practices that determine why and how particular sciences and technologies have gained relevance and resonance in society, and why and how they take part in constitutional moments in supranational and global domains (Jasanoff, 2003).

The outline given is also meant to support two methodological conclusions. First, the analysis of the configuration of politics and science in today's world of rapid transition requires comparative perspectives, because otherwise the social science investigation falls short of the complexity and empirical variety of reality. It also helps achieve more appropriate evaluations of hypotheses about new social phenomena.

Second, transnational perspectives are needed because today's configuration of politics and science extends across various institutional levels that are not just differentiated but also connected with each other in multiple ways. Despite the prevalence of perspectives rooted in the nation state, there have always been transnational perspectives in the social sciences, for example, in the work of Karl Marx and Max Weber. Yet now there is a clear demand for, and shift towards, such perspectives, as the debates on globalization, world society, or "methodological nationalism" (Beck, 2005) indicate. In other words, investigations focusing on changing regimes or shifting boundaries between science and politics are clearly limited if they do not take into account comparative or transnational perspectives (Jasanoff, 2005; 1997).

While I have tried to make clear that both perspectives are fundamentally important, two basic issues need further elaboration: first, the design of comparative analysis depending on the research subject and the questions asked; and second, the definition of transnationality as regards the forms of interdependency among the various levels and areas in the configuration of politics and science. At the

same time, further clarification is needed of how to distinguish among transnationality, internationality, and globality.

However, it would be misleading to neglect the importance of cross-national comparisons. Not only does transnationality presuppose 'nationality,' but diverging political, social, and cultural institutions and traditions also account for different understandings of, and responses to, transnationality.

Let us come back to the beginning, to the question of what is new in the relationship between science and politics. It is not the increasing connectivity of science and politics as such that marks change. The changes are more 'limited' and concern, put briefly, the 'vertical' differentiation and transnational extension, as well as the mutual pervasion of politics and science, and the increasing significance of market-orientations as well as of social accountability in the relationship between science and politics. Since these trends do not account for a uniform mode of change, they rather point to tensions and contradictions. This situation thus reconfirms the basic open-ended nature of social change, and the challenges to analyzing and understanding it.

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