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Editorial
The Challenge of Complexity

The socio-technical systems of modern societies — such as the energy system or the financial markets — are complex systems. They are complex because of the number of interconnected components and the degree of interdependence between the actors, organizations, institutions and technologies involved. Attempts to govern these systems often fail or fall short of reaching their goals.

The article of Gerhard Fuchs and Sandra Wassermann analyzes the transformation of the energy system. It argues that successful innovations in the field of renewable energies depend on advocacy coalitions and the creation of niche markets – thus referring to the article of Rüdiger Mautz, which was published in the last issue (1/08) of STI-Studies.

Ekatarina Svetlova deals with the strategies of portfolio managers in financial markets to cope with the everyday challenge of complexity. She argues that complexity is a necessary ingredient of markets, which is reproduced by the heterogeneity of actors' attempts to reduce complexity.

Due to different technical reasons, this issue contains only two articles. But we are facing subsequent issues with a 'normal' number of contributions.

Ingo Schulz-Schaeffer

Raymund Werle

Johannes Weyer

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Picking a Winner?

Innovation in Photovoltaics and the Political Creation of Niche Markets

Gerhard Fuchs, Sandra Wassermann (University of Stuttgart)

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Abstract

Innovation theory has pointed to the complex, non-linear character of innovation processes. Heterogeneous networks of actors including a mixed spectrum of many and diverse academic, economic, and governmental agencies combine to achieve innovations. Is there any role for innovation policy beyond influencing framework conditions in such a situation? The article analyzes the case of a successful innovation in the energy sector: photovoltaics. It argues that - given the special characteristics of the energy sector – successful innovation depended on strong political support and an advocacy coalition, which achieved institutional backing. The method chosen to realize the innovation was the creation of a niche market with the help of regulatory instruments.

1 Introduction

The energy system in industrialized nations is changing in what can be seen as an example of a technological and institutional regime change. Victor (2002) sees the sector in its third structural transformation. The exact outcome of this regime change is uncertain. But one element of a future new governance structure will be an increasing importance of decentralized forms of electric power generation, a shift towards more environmentally sustainable technologies, e.g. renewable energy technologies, which in the past were pushed forward by a coalition of diverse actors. One of the innovative developments in the area of renewable energy technologies will be analyzed in this article: photovoltaics (PV).

We will use a broad lens in order to examine the growth of PV both as a source of electric power generation and as a business sector in Germany. PV can be considered as an unusual success story in which the ability of state authorities to strongly influence renewable energy production and associated economic activity becomes apparent.

It will be argued that the growth of renewable energy proceeds within networks of governance, which comprise formal regimes at multiple levels, informal norms and practices as well as market structures and processes. These networks involve national and sub-national authorities, multilateral institutions, firms and NGOs. Technological development and market growth of PV are thus viewed as embedded in a broad social, economic, and political system of governance. Corporate strategies, social movements and public policy constitute this sector's essential elements of governance. We will further argue that PV policy in Germany is characterized by a commitment to a specific mission, a concertation of the main actors, a long term orientation and substantive subsidies. Insofar PV appears as a successful "planned" innovation, rarely found in the relevant literature. Caniels/Romijn (2008: 246) have argued that the literature on strategic niche management is short of success stories. Thus, we know little about the processes by which (policy and technological) experiments can ultimately culminate in viable market niches that ultimately will contribute to a regime change in a specific sector. The present article will try to fill this gap.

We will start with a clarification of our concept of innovation and then describe the elements of the technological system PV. Based on this we will discuss the ingredients of the success story. At the moment it would be foolish to claim that PV will remain a success story in the future and eventually play a dominant role in the development of a new energy regime. PV is growing but it is still in its infant state – albeit already bigger than many "established" sectors. Only few publications have focused on the particular technological and institutional prerequisites, which enabled photovoltaics to become a real success story, outcompeting – from an innovation perspective – other energy technologies.

2 Innovation and Sectoral Systems of Innovation

Before discussing the German innovation policy focussing on the development and market expansion of photovoltaics, we have to outline the conceptual framework of our analysis. We start with some general reflections on innovation and innovation policy, drawing on the literature on systems of innovation and strategic niche management on the one hand and the advocacy coalition approach on the other.

2.1 Innovation Policy

Since the 1990s a global policy-shift towards research and technology can be observed: the promotion of innovation has become the centre piece of official national as well as of supra- and sub-national policies. This shift in emphasis reflects discussions on the role of the state in promoting technology as well as new ideas about how new technologies become successful on the markets.

The *traditional model in research and technology policies* either centred on the support of basic research which eventually should bring about new technologies ripe for the markets (technology push) or opted for a mission oriented approach promoting a specific new technology and financing its development by certain companies or research laboratories. (cf. Hiskes/Hiskes 1986)

Innovation research, however, has shown that there is no linear development of technological innovation towards successful adoption and diffusion (cf. Van de Ven et al. 1999). Support of basic research does not guarantee the eventual development of products that become widely accepted and thus achieve commercial success. But exactly "success on the market" seems to become top priority in times of increasing worldwide competition on crowded markets. The introduction of new, innovative products is considered to be a precondition for keeping a competitive edge.

In parallel discussions on the steering capacities of the state a dire picture was painted, accentuating the conviction that the state cannot successfully choose technologies, which will later be a success on the market. Along with an increasingly prevalent attitude that markets are the best innovators and should be left alone, policy instruments worldwide seemed to converge (cf. Holzinger/Jörgens/Knill 2007). This neoliberal understanding, the support of market dominance and "the retreat of the state" (Strange 1996) emerged in the 1990s, and was accompanied by new types of policies and policy instruments, which also affected the conception of technology policy. Research and technology policy has now turned into innovation policy and mainly focuses on funding basic research and networking activities – in particular joint projects between firms and research institutes – in order to stimulate knowledge flows and to ensure that results in scientific research may be used and adopted commercially (cf. Nooteboom 1999, Edquist 2001:18). Networks may facilitate producer-customer relationships or even result in the creation of an advocacy coalition, which experts consider an important pre-condition for successful radical innovations (cf. Weimer-Jehle/Fuchs 2007).

Although the market discourse has achieved nearly universal legitimacy, counter tendencies have always been visible as well. One of the policy measures relying more on the activities of public actors is the politically supported *creation of niche markets*. This new form of innovation policy selects a certain technology (or its pre-stage) in advance and tries to speed up its development, and even might help to shape the mode of its application. Such politically created niche markets work through market stimulation programmes, like subsidies or the provision of soft loans for prospective customers, as well as through modes of legitimizing the developing technology in order to raise its public acceptance (cf. Edler 2007). Especially in the area of environmental technologies, strategic niche management has increasingly become accepted as an instrument of innovation policy (cf. Kemp et al 1998; Kemp 2002; Coenen 2002) with the hope that even a transformation of a whole technological regime can be enabled (cf. Berkhout et al 2003: 4; Caniels/Romijn 2008).

But in both cases the actual design of national policies has to consider existing institutional frameworks and socio-cultural conditions. Studies in the tradition of the Varieties of Capitalism approach (Hall/Soskice 2001) claim, that if national innovation policy stresses and uses national comparative institutional advantages, it can be more successful. In other words a system dominated by non-market coordination will have difficulties pushing new technologies dependent on a flexible and quick functioning of market mechanisms. While on the other hand the support of technologies which require the non-market coordination of various actors will be difficult in liberal market economies. Based on this highly stylised interpretation we argue that the creation of (sheltered) niche markets can be a successful policy instrument especially in coordinated market economies (hypothesis 1).

Considering the fact, that photovoltaics can be seen as a technological innovation that is supported in order to transform the energy sector, the existence of political and social forces which strongly oppose photovoltaics due to ideological and economic (rent seeking) reasons can be assumed. As Jänicke has shown, changes in actor constellations have resulted in improved terms for innovation in environmentally friendly products (cf. 1997: 7). With regard to actor constellations and situational factors enhancing policy change, the policy analysis literature refers to the role of advocacy coalitions that are crucially important in order to spur institutional or cultural changes (cf. Litfin 2000). Therefore we argue that the success of innovation policy depends on its ability to create and mobilise an advocacy coalition supporting the aimed technology, especially if strong incumbent actors (like in the established energy system) exist (hypothesis 2).

2.2 Innovation

Innovation can be defined as artefacts, processes, ideas, strategies, which successfully change routines and are embedded in specific contexts of development and usage. Innovation as such is not just a new idea or technical system, but one, which is being successfully implemented. Including the processes of implementation, however, it becomes difficult to disentangle e.g. the technical artefact from the way it is being developed and used.

Innovation in this sense is not a linear process but occurs by interactive relationships and feedback mechanisms between institutional and organisational elements of science, technology, learning, production, policy, firms and potential or actual market demand. Some technologies may only become innovations due to interactions between producers and users or the specific way; customers use and apply new technical artefacts (cf. Malerba 2004: 24). The acceptance and use of a new technology at any rate plays a crucial role in the innovation process. Thus new – better – technologies in our context are only referred to as innovations, if they find their way to the market.

2.3 Innovation and Uncertainty

It is generally acknowledged that every (economic) activity has to face the problem of uncertainty (Beckert 1996). This is even more so in the case of innovations, particularly if potential new products would have to cope with incumbent products and existing infrastructures and routines supporting them. Proven ways to cope with uncertainty are the development and reliance on routines, customs, regulations, established institutions etc.

Innovating firms may not know which application or design a new technology should be given in order to be successful in the market. This can lead firms to hesitate implementing significant changes, even as they face a volatile environment that increases pressures to introduce new products, seek new markets and introduce new technologies, practices and organisational methods into their production processes. Uncertainty can also make it more difficult for firms to obtain external funding for their innovation projects. Customers may not trust a new and unproven technology. This leads to another mechanism blocking the diffusion of a new technology, which is lack of legitimacy.

We are here confronted with the paradox that innovation as a routine changing mechanism, nevertheless also depends on routines, albeit newly developing ones. Therefore innovation policy can aim to reduce uncertainty by establishing a mix of policy instruments along with a viable support coalition. Whenever, e.g. innovation policy can provide technological developments with legitimacy, the financial system will become more willing to invest in innovative firms and potential customers may feel more safe and be more induced to purchase new technologies (cf. Carlsson/Jacobsson 1997: 285).

The role of uncertainty can be seen very clearly if we look at the developments in the 1990s when the German PV industry was close to become extinct. Production facilities were moved, since producers considered it uncertain whether the institutional framework in Germany could provide favourable conditions for the further development of the PV industry.

As Edquist suggests, a systemic view on innovation policy should not only analyse the role of the state but also include feedback mechanisms to find out how the rest of the system, social structures, routines or even discrete occurrences influence innovation policies (cf. 2001: 17). German governance has always been characterised by close linkages and common interests between government, industry, business associations and unions (cf. Hall/Soskice 2001; Harding 2000). This established arrangement has shaped German innovation policies and most probably will also do so in the case of PV.

2.4 The Transformation of Electric Power Generation

Photovoltaics is treated as an innovation within and for the industrial sector of electric power generation. As already briefly mentioned this sector is undergoing severe changes in nearly all industrialized nations. The dynamics leading to these changes are also important to understand the case of PV, because they opened up a window of opportunity, which helped to push forward this new option.

The traditional electric power system can be characterized as a large technical system (cf. Mayntz/Hughes 1988) with tightly coupled components run by a few, powerful incumbent actors. Energy generation is highly centralized in big power stations, open markets hardly exist. Price regulation and fixation is common and huge subsidies for the development of old and new technologies (e.g. coal, nuclear energy) make it difficult to determine "real" prizes. It is suggested that the costs of producing electricity, gained out of coal or oil would double, if intransparent external costs were taken into account (cf. Milborrow 2002: 32). Incumbent energy technologies have received direct and indirect subsidies for decades (cf. Jacobsson/Bergek 2004: 210). R&D expenditures in these closed markets are nevertheless low and innovation is slow moving and incremental. R&D expenditures to a very large degree depend on the interpretation of political signals regarding the regulation of technology.

Two trends that challenge the traditional ways of power generation can be observed: the liberalisation of infrastructures and environmental issues such as the "global warming". Hopes that an effective regime to address climate change will emerge have shifted from the emphasis on a mandatory multilateral agreement, the Kyoto protocol, to a plethora of regional, national, and sub-national programs and initiatives. Policy responses include carbon emission limits and trading systems, direct subsidies for renewables, and renewable portfolio standards that mandate the use of specific volumes of renewable energy in electricity generation. Such policy initiatives are required because the market will not, by itself, respond adequately to the environmental challenge. Given the rapid growth expected in global markets for low-emission technologies, the policy agenda is also driven by economic development goals, as countries vie for competitiveness and market share in these emerging fields. Liberalization can have diverging effects on renewable energies. If energy prices fall as a result of liberalization and increasing market competition (as the pure theory would make us expect) the price targets that renewables must meet become more challenging and liberalization might prove to be an impediment for their further spread. On the other hand, policies and systems such as quotas and renewable energy certificates can be compatible with more competitive market structures as the experiences of the last years have shown when energy prices increased considerably. In fact, many of the policies that have been implemented to support renewables operate within the framework of liberal markets. (Cf. OECD 2008)

Finally, beyond the problems of a lack of transparency and the prevalence of risk-averse actors, there is the constraint of centralized energy infrastructures, which have developed and become established throughout decades. National grids are mainly tailored to the operation of centralized power plants and thus support their existence. Alternative technologies like photovoltaics follow an opposite decentralised logic that does not easily fit into the established technological concepts. Thus, PV has difficulties competing with the incumbent technologies (cf. Stern 2006: 355).

In sum this has led to the widely accepted conviction that policy instruments to create niche markets for renewable energies were needed. Even the European Commission, traditionally favouring market instruments and being quite critical towards demand side policy actions, has opted for market stimulation programmes for renewable energy technologies (cf. European Commission 2005; Directive 2001/77/EC). This is true in spite of the fact that until recently the European Commission and the OECD both had disapproved the German model of market stimulation and instead had favoured quota models which use market signals in order to increase the supply of renewable energy (cf. Busch 2005: 235).

3 Photovoltaics: Characteristics of the technology

Analysing the photovoltaics success story, we need to give a short introduction to the technologies and applications we are talking about. Photovoltaics use solar cells to produce electric power[1]. The most common type of solar cell consists of either mono-crystalline or poly-crystalline silicon, which is conventionally produced and used in the electronics (semiconductor) industry. Crystalline silicon technologies represent a 93 % share of the photovoltaics world market (cf. Solarbuzz 2007). Mono-crystalline silicon cells are characterised by their ability to convert a relatively large section of the light spectrum into electricity with an efficiency of up to 24,7 per cent under ideal laboratory conditions (cf. Solarserver 2007). Poly-crystalline silicon cells do not achieve such high efficiencies, but they compensate it with price-advantages. The same holds for amorphous and other 'thin film' technologies that consist of cadmium telluride (CdTe) or copper indium diselenide (CIS). Due to silicon shortages for several years now, research and develop-

[1] Photovoltaics should not to be mixed up with solar-thermy, which uses solar radiation to produce heat.

ment on non-silicon thin film technologies has become increasingly popular and remarkable reductions in production costs have been achieved.

The French physicist Alexandre Becquerel first discovered the photovoltaic effect in 1839. Albert Einstein's theoretical work on the photovoltaic effect won the Nobel Prize in 1921. This illustrates that basic research on photovoltaics has been carried out for decades. But first applications did not appear until the 1950s, when Bell Laboratories invented the first solar cell and the US government started to use solar cells for satellites.

> "The satellite market became the first significant commercial market and annual production rose to about 0,1 MWp per year in the late 1960s." (cf. Jacobsson et al 2002: 10)

It is striking that the first satellite project using solar power was under US Navy management and monitored by the Department of Defense. Some authors therefore pointed out that photovoltaics was just the case of another technology for which the role of the military was crucial in the innovation process (cf. Clark/Juma 1987: 142, Jacobsson et al 2002: 10). Due to US export restrictions the European Space Agency had to rely on German companies like Siemens and Telefunken to get involved in photovoltaics research and production for space programs in the 1960s (cf. Jacobsson et al 2002: 16). Since the 1970s and largely owing to the oil crises, interest in the development of various terrestrial applications grew and led to further R&D activities, mainly in the USA and Japan. A range of off-grid applications emerged, that were mainly used for consumer electronics like calculators and watches or as stand-alone 'power stations' for SOS telephones and in remote places like alpine huts and camping sites. Beyond this the idea of solar home systems for developing countries came up. Rather distinct from these off-grid photovoltaics are newer forms of applications that supply electricity to the grid just as conventional power technologies. Grid-connected applications can be found as roof-top systems, ground-mounted systems or as systems integrated into house façades. However, early projects demonstrating how to use photovoltaics in order to supply electricity to the grid did not appear before the 1990s. Thus grid-connected photovoltaics is a rather new development. It is therefore striking that since 1999 in IEA (International Energy Agency) reporting countries grid-connected photovoltaics has rapidly outpaced other applications (cf. IEA 2005).

4 Promoting photovoltaics

In the following we will analyse the development of photovoltaics based on the hypothesis that an advocacy coalition is a crucial mechanism behind the formulation and implementation of innovation policies.

> "Private firms, state agencies and other organisations often act with the objective to influence innovation policies in order to get them designed and implemented in their own interest" (cf. Edquist 2001: 20).

So called advocacy coalitions supporting environmental policies consist of administrative and academic environmentalists as well as members of environmental social movements who cooperate with industrial actors, such as manufacturers of renewable energy technologies (cf. Jänicke 2007: 140). But since lobbyism is often a conservative mechanism, as it requires that the lobbyists have an economic power position, one would not assume that environmentalists were able to form an effective advocacy coalition. Interest groups, which support emerging technologies, are normally neither well positioned financially nor do they have access to powerful political actors.

Even though the advocacy coalition for photovoltaics was not formed by powerful actors and groups, it intelligently managed to use external events to gain strong social backing for its ideas, which was needed, as it faced powerful opposition by the incumbent energy producers.

> "Substituting established technologies implies, (…), that new interest groups will challenge existing ones, and a realignment of the institutional framework, and a transformation of the energy system cannot be expected to be achieved without overcoming considerable opposition from vested interests involved with the incumbent technologies." (Jacobsson et al 2002: 3)

4.1 The formative stage (1970s – 1990s)

The story of PV began like many other cases of German research policy. Starting in the early eighties the common instruments for the public funding of research and development like institutional funding of relevant research departments doing basic research were used. The external trigger for early research had been the oil crisis in the 1970s. At that time the ministry of research and technology (BMFT) was in charge of photovoltaics policy programs. Initially the support for new technology had been integrated into the unit for non-nuclear energy technologies. In 1976, an independent unit was created (cf. Ristau 1998: 40). Interestingly, many of the programs to finance photovoltaics projects, were carried out by the ministry of economic cooperation and development, because during the 1970s the future of photovoltaics applications was seen in solar home systems for developing countries, i.e. the focus was on off-grid applications.

First steps towards an advocacy coalition in the 1980s

When oil prices had settled down again and with the beginning of the conservative-liberal coalition under Chancellor Kohl, policy actions in order to promote photovoltaics declined severely. In 1985 public funding of photovoltaics related research and development projects did not account for more than 53 Mio DM. Albeit institutional actors involved in research on photovoltaics had been established and later on, when other external events like the Chernobyl accident occurred and discussions on environmental problems or on climate change appeared, they managed, together with environmentalist groups, to set the agenda for photovoltaics. When political actors put environmental problems higher on the political agenda, the Green party on the one hand and highly motivated researchers on the other hand acted as transmission belts between external events and political and social discourses.

In the 1980s specialized photovoltaics departments and research institutes had been created, like the Fraunhofer Institut für Solare Energiesysteme in Freiburg (in 1982), the Zentrum für Sonnenenergie- und Wasserstoff-Forschung in Stuttgart/Ulm (in 1988) or specialized physics departments, for example at the Carl von Ossietzky University of Oldenburg. The latter can be seen as a typical example of how the formation of the photovoltaics advocacy coalition depended on highly committed individual actors. They were influenced by the experiences made by early anti-nuclear power activists, who were criticized for their lack of reasonable alternatives for energy provision (cf. Gabler 2007). The formation of research groups and departments dedicated to the development of alternatives to nuclear power became the first strategic step towards the formation of an advocacy coalition supporting photovoltaics. Furthermore, the creation of specialized departments and institutes attracted environmentally committed scientists, and later local networks consisting of environmentalists and researchers emerged. A prominent case is Freiburg, where the Fraunhofer Institut für Solare Energiesysteme merged with a vivid environmental scene that positively influenced network activities and enabled local strategies of niche management (cf. Niewienda 2006).

Federal innovation policy at that time became mainly direct project funding.

The main recipients were the Fraunhofer Institute for Solar Energy Systems, the Hahn-Meitner-Institute, the Institute for Solar Energy Supply Techniques and two industrial actors, AEG-Telefunken and Siemens Solar. The early photovoltaics programs "(…) provided opportunities for universities, institutes and firms to search in many directions, which was sensible given the underlying uncertainties with respect to technologies and markets" (cf. Jacobsson/Lauber 2006: 262). Research funding was not only dedicated to one technology. Rather, competing technologies, such as crystalline silicon and thin-film technologies were supported. And additionally, research and development of inverters (to make grid-connected applications work) had started.

Interestingly, these research projects on the one hand, and the absence of market stimulation programs on the other hand, led to the weird situation, that the big two German companies engaged in photovoltaics production managed to develop internationally competitive products. German research on photovoltaics achieved a leading position alongside Japan and the United States, but the technologies developed could not be sold at home due to a lack of domestic demand (cf. Ristau 1998: 45). Actually, photovoltaics technologies developed in Germany were ready for testing. However, owing to the characteristics of the energy sector, coupled with the difficulties of creating private demand and the absence of political interest and financial support it was unlikely that photovoltaics could succeed on the German market. The supporting advocacy coalition was in its infancy, consisting only of highly committed scientists, environmental groups (cf Gabler 2007) and a first association, the newly founded Deutsche Gesellschaft für Solar (DGS). In these early days the advocacy coalition was too weak, particularly as it had not yet incorporated more powerful industrial lobbies. At the same time influential lobby groups supporting fossil fuels and nuclear power worked hard to prevent competition from renewable energies. They joined forces with the ministry of economics (cf. Ristau 1998: 46) and heavily relied on old research and development contacts and networks within the ministry of research (cf. Ristau 1998: 44).

But then external events such as the nuclear accident in Chernobyl in 1986 changed public opinion and attitudes towards nuclear power substantially. These events opened a window of opportunity for a general discussion on a transformation of the energy sector. Within two years opposition against nuclear energy increased from 50% to over 70% (cf. Jahn 1992). While prior to Chernobyl only the Green party had argued against nuclear power, this position was now also adopted by the Social Democrats, who opted for phasing out nuclear power plants. In addition to the national antipathy towards nuclear energy the influence of a growing Green party as well as powerful environmental movements have clearly to be mentioned. Considering all these circumstances, the German government – compared to other European governments – at a relatively early stage felt compelled to support research, development as well as diffusion of renewable energy technologies, such as photovoltaics.

Market stimulation in the early 1990s

Market stimulation programs are traditionally policy instruments of the ministry of economics, but these instruments have not been applied until 1991. As we have mentioned before, the ministry of economics deliberately refused to support the photovoltaics research and development projects of the ministry of research. And since the new technology could definitely not be economically competitive in Germany, it either had to fail, find its markets abroad (in Southern regions, as off grid applications in the developing world) or get domestic support in terms of an artificial niche market. Finally in 1991, the situation changed when the first feed-in-law was developed and passed. It described a mechanism based on which utilities were obliged to remunerate energy of renewable sources fed into the grid. Producers of renewable electric power received 90% of the average revenue per kilowatt-hour from the utilities. Even though the first feed-in-law was sort of a market stimulation program, it contained a market mechanism, which at the beginning was not seen as critical. But with energy prices declining throughout the 1990s (mainly due to European deregulation policies), this policy instrument emerged as being too weak to trigger market expansion for photovoltaics.

This first feed-in-law was accompanied by the 1000-roofs-program in the early 1990s, which enabled first experiences with grid-connected photovoltaics applications and thus can be interpreted as a typical instrument of strategic niche management. This program that started in 1991 and ended in 1995 was a mixture of demonstration and market stimulation. It offered soft loans for private households, which were interested in participating in the grid-connected photovoltaics test stage. The program was not only accompanied by electro-technical and physical tests on inverters, cell duration etc., but also by social research which studied customers' motives and social affiliations (cf. Gennenig/Hoffmann 1996). This first niche program became crucial for institutional capacity building and symbolized an initial step towards a transformation of the energy sector. Routines and motives of first movers could be revealed, and thus enabled the advocacy coalition to improve its diffusion strategy, for example by better taking into account special needs of potential users. In addition, the program helped photovoltaics to gain more public awareness. Backed by the feed-in-law, which obliged utilities to remunerate energy of renewable sources fed into the grid, the improvement of inverters laid the grounds for structural changes within the energy sector, abandoning traditional centralised grid systems, giving way to decentralised, environmental friendly systems, such as grid connected photovoltaics applications.

When the 1000-roofs-program ended and the German government did not immediately develop follow-up programs, "(…) one could observe a shift in the investment activities of the big European PV-companies from Europe towards the US" (Jäger-Waldau 2002: 40). The ministry of economics (BMWi) started a market launch program for renewable energy technologies in 1995. But since this program only provided 4.5 Mio. DM for photovoltaics, it did not meet the expectations of the photovoltaics industry (cf. Ristau 1998). This is a striking example for the relationship between uncertainty and innovation. Throughout the 1990s the German policy did not systematically target at uncertainty. Its programs were inadequately financed and not based on long-term considerations. As a result the development of technical innovations and marketable products came to a halt. This only changed, when the Green party together with the Social Democrats came into power in 1998.

Despite these shortcomings, it has to be admitted, that the 1990s can be characterised by early (successful) investments. Public funded R&D, as well as the first market stimulation programs and the first feed-in law did not only lead to the build-up of an initial knowledge base. It also enabled the creation of an embryonic advocacy coalition consisting of scientists, an infant industry and its interest organisations, as well as highly committed environmentalists. Some of them appeared as first movers on the market, which means they were the first costumers participating in the 1000-roof program. Even though the programme offered soft loans, and the power produced was remunerated, these first users did not benefit from their investment in a monetary sense. Instead they appeared as 'the hard core' of the advocacy coalition, mainly acting out of ideological reasons. But the early investments and the ideological commitments triggered positive feedbacks, which for example resulted in the ability of the coalition to shape further institutional change and to initiate sectoral transformation. Taken together the first political programs had significant effects. First of all public awareness of the new technology rose and photovoltaics was provided with legitimacy. Public and social acceptance as well as political support of the technology was achieved, subsidies became widely approved. Furthermore, a number of new, often small firms entered the market, "(…) among these, we find both module manufacturers and integrators of solar cells into facades and roofs, the latter moving the market for solar cells into new applications" (Jacobsson/Lauber 2006: 266). Prior to this, the two big players, Siemens and AEG Telefunken dominated the market. Just to give an idea: in 1991, when the 1000-roofs-program was launched, 99.5% of the induced market demand was satisfied by these two companies. And even in 1993 when the program was opened for European competitors like BP-Solar and the Italian firm Helios, Siemens and ASE still held a 70% market share (cf. Ristau 1998: 48).

Strategic niche management in the 1990s

Throughout the 1990s, industrial (solar) associations were gradually founded, which aimed to improve and enhance political support of the infant technology and its commercialization. Additionally, (local) groups and societies, like the Aachen Solarverein, Eurosolar and Förderverein Solarenergie were founded and discussed the suitability of political instruments. They developed blue prints for a new feed-in-law or another roof-program and tried to build up political momentum. Local politicians, who strongly favoured the idea of renewable energies and opted for more decentralised energy systems, joined them. To them, grid-connected photovoltaics applications met both of these aims. It was a coalition of local politicians, the Green party, researchers, environmental societies and business associations that managed to influence the federal government to improve and enhance its innovation policy for photovoltaics. Especially when the 1000-roofs-program ended, strategic niche management appeared on the local level: protagonists of the solar scene were successful in implementing local feed-in-laws, inspired by the Aachen Solarverein. In contrast to the federal law, which only regulated the remuneration of photovoltaics power at arm's length, the concept of the Aachen Solarverein provided cost-covering prices. The development of a policy instrument that aims to convince users purchasing PV for return on investment reasons can be interpreted as a change in secondary aspects. Still adhering to its policy core, the PV coalition has learned new ways to achieve its goal. Thus the new mechanism provided an opportunity for the wider diffusion of photovoltaics in a way that was not only attractive to ideological environmentalists as potential users, but photovoltaics became also an interesting option for non-ideological customers (beyond the initial advocacy coalition) to earn money.

These initiatives were strongly supported by the infant photovoltaics industry and its associations. The solar industry intensified its lobbying, and in particular due to some of the global players that were also involved in cell production, like Siemens and ASE becoming part of the advocacy coalition, political pressure began to become more effective. Siemens, which was already producing in the USA, complained, that due to the lack of domestic demand in Germany, it would not make sense, coming back to Germany, and ASE threatened to follow Siemens if no follow up program would be started. In reaction the federal government started a debate on the 100.000-roofs-program. This long-term-perspective for public funding i.e. creating a niche market was the reason for ASE to stay in Germany and even build up new production plants. It increased its capacity from 20 to 50 MW by the end of 2002 under the name of RWE-Schott Solar (cf. Jacobsson/Lauber 2006:268).

In the PV coalition's formative stage significant opposition arose. Industrial organizations, especially German utilities strongly opposed political instruments to support photovoltaics, such as the early energy-feed-in-law from 1991 (cf. Wong 2005: 135). In 1994 Preussen Elektra lodged a complaint against this law at the European and the German federal level. Opposition was not only voiced as a general critique of subsidizing renewable energy technologies, but it was also targeted at the specific design of the feed-in law, which indeed disadvantaged some of the utilities. Since renewable energy is mainly produced in the windy regions nearby the coast (wind power) and photovoltaics applications are concentrated in the sunny South, the bias led to the situation, that some of the Northern utilities or their customers respectively, had to finance subsidies for renewable energy technologies. The case was dismissed, but the discussion did not stop.

4.2 Take-off (1998 - 2007)

Following Sabatier's argument, policy change can only be achieved acommodating external perturbations, such as changes in the government coalition or impacts from other subsystems. This seems also to be true for the case of PV. When in 1998 the Green party, together with the Social Democrats formed the federal government, the photovoltaics advocacy coalition took its chance. Rather than trying to have an impact on energy policy from outside it now could directly influence the rebuilding of institutional frames and policy programs. The Greens took over the ministry of the environment and this initiated the institutionalization of the photovoltaics advocacy coalition within the centre of political power. The situation in the late 1990s was accompanied by international and European trends, such as the liberalization and deregulation of the energy sector and an increased focus of international institutions as well as the European Commission on CO2 reduction as a political target with top priority, initiated by the Kyoto protocol.

As a consequence of the change in political power constellations a restructuring of the energy sector began. Institutional settings and the infrastructure of the energy sector became more open and fluent. Corporate structures were being reorganised and replaced by more competitive management and governance structures. Thus innovation in photovoltaics was accompanied by the re-structuring of the energy sector and social innovations like new management concepts, new user routines, "new roles and identities of electricity customers, new policy problems, regulatory concepts, institutions and governance arrangements" (cf. Voß et al. 2003: 4). These transformation processes have been crucial factors to trigger innovation in photovoltaics because they opened the window of opportunity for the success of an advocacy coalition against the resistance of the powerful advocates of incumbent energy sources.

The stabilisation of the advocacy coalition

Two policy instruments were designed and implemented, which are widely appreciated as having been decisive for the German photovoltaics success story. The actual design of the instruments has been prepared and debated by solar groups, societies and associations. Groups like Eurosolar, Förderverein Solarenergie and Greenpeace were extremely important for an adjusted 'relaunch' of the former 1000-roofs-program.

In 1999 the program, which aimed at a market stimulation, was launched. It offered soft loans with 10 years duration and the redemption starting in the third year. In 2000 the Renewable Energy Law was passed. It set a feed-in tariff of around 50 Cent[2] per kWh fixed for 20 years, with a 5% decrease annually for later installations from 2002 on. Compared to the first feed-in-law, which had been heavily opposed by the utilities, the additional costs of renewable energies were now shared and only five per cent of the financial charges had to be paid by the utilities. The law was inspired by the local feed-in laws for solar power as the learning effects which had been achieved on the local level helped the Greens to move the concept to the federal level. For this process it was extremely helpful that one of the main protagonists of the local groups, which had organized local feed-in tariffs, was elected as a federal deputy in 1998 and thus could bring in experiences he had made on the local level (cf. Rosenbaum et al 2005: 79). He was among the Green deputies, who initiated a discursive process involving various actors, such as environmental groups, solar industry associations, the association of the machinery and equipment producers VDMA, the metalworkers trade union, solar cell producers and politicians from some *Länder.* This institutionalization of an intermediate level of conflict can be interpreted referring to Sabatier's concept of policy learning. The panel did not intend to conduct a general discussion on the future of the German energy system (the policy core, still separating the coalitions), instead it only discussed the issue of financial support for renewable energy technologies. Hence, in 1998 the Green party acted as a policy broker, searching for compromises in secondary aspects that could be supported by the majority of actors. This facilitated the enlargement and stabilization of the advocacy coalition in a way that guaranteed its survival even without institutional backing in the future.

"The unorthodox coalition even included a major utility (…); as a result the big utilities were not united in their opposition." (Jacobsson/Lauber 2006: 267)

Besides innovation in PV was still supported by public research money – albeit in a decreasing manner. Public money became concentrated on network and cluster projects, many of them part of structural policies in order to help the economically underdeveloped regions in the East of Germany. Regional cluster and network policy is a rather new policy instrument that aims to create an innovation friendly environment by fostering collective identities and trust to support the formation and elaboration of local networks (cf. Dohse 2007). Within the last years, the solar industry has well understood where to settle down in order to receive subsidies. Several photovoltaics clusters have been established in East Germany especially in the small town of Thalheim nearby Bitterfeld in Saxony-Anhalt. Particularly small start-ups, which emerged after 2000, have settled down in the Eastern regions. One of the world leaders in cell production became Q-Cells, a firm, founded in Berlin in 1999, which soon moved to Thalheim in order to start cell production in 2001. Q-Cells is one example of Germany's *success story*. It perfectly reflects the effectiveness of the 100.000-roofs-program and the Renewable Energy Law. At the end of 2002 Q-Cells employed 82 persons, at the end of 2004 it already had 484 employees, a number which has grown to 1.700 at the end of 2007.

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[2] The exact amount is subject to size and application: electricity from rooftop systems is reimbursed higher than electricity sourced from ground-mounted systems.

Q-Cells also can serve as an example on how the photovoltaics industry is now increasingly able to get financing and venture capital from the private sector and the equity market. Since October 2005 Q-Cells is listed on the Frankfurt stock exchange, and since December 2005 it is included in the technology index TecDax of the German stock exchange. This shows that the industry has left the formative stage, i.e. the niche market and has been entering the take off stage – ready for market expansion.

Market expansion and growing public acceptance

The take-off stage is characterized by a significant enlargement and diversification of the photovoltaics advocacy coalition. This applies to producers as well as to users. Whereas first producers like the Freiburg Solar-Fabrik, founded in 1996 by the environmentalist Georg Salvamoser, were embedded in local solar networks and were not solely led by return on investment thinking, motives and behaviours of producers like Q-Cells do not differ from producers in other sectors. Additionally, due to the Renewable Energy Law, users of photovoltaics are not any longer necessarily led by 'green' motives, as it has increasingly become profitable to purchase solar modules, especially for farmers, who have plenty of space on their barn roofs, which can be used as building ground for the rather cheap thin film technology (cf. Rosenbaum et al 2005: 85f.).[3] Furthermore, this development is accompanied by the wide acceptance of solar energy within the German public. This trend is vividly reflected in the Christian Democratic party, which now has well accepted the strategy of creating a niche market for photovoltaics. Thus, when in 2005 the Red-Green government ended and was replaced by the grand coalition of Social Democrats and Christian Democrats, the new government did not opt for striking a new path. The Renewable Energy Law was not abolished and it is save to say, that the amendment of the law does not entail comprehensive changes for PV support.

The take-off stage has also been accompanied by organizational changes, which helped to consolidate the chosen path. In 2002, after the re-election of the Red-Green government, the coalition parties agreed that the ministry of the environment should obtain full responsibility for renewable energies. Whereas the beginning of the formative stage had been characterised by conflicts of competences between the ministry of economics and the ministry of research, and both being rather averse to substantially supporting photovoltaics, in 2002 the situation completely changed. The ministry of the environment is now responsible for the Renewable Energy Law as well as the public financing of photovoltaics related R&D.[4]

Meanwhile the photovoltaics industry in Germany is highly differentiated, as concerns the command of competing technologies and in the capability to set up important links to surrounding industries. Therefore photovoltaics related R&D is not just research on new materials and cell efficiencies. An increasing number of projects is funded which carry out research on inverters. This also holds true for the firms, which produce the technology.

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[3] The literature on strategic niche management sees the prevalence of economic motives as an impediment to the success of policies (Hoogma et al. 2002). We are arguing that exactly the opposite mechanism (addressing economic motives) has been essential for the success of PV policies.

[4] Other elements of institutionalization are the so-called 'Glottertal talks', which are strategic talks on photovoltaics related R&D. These talks originated in 1987, but have gained importance particularly during the last couple of years. Researchers and representatives of the leading institutes and companies meet with members of the ministry of the environment in order to discuss future public R&D activities for PV.

„For instance, in 2000, there were ten firms showing roof integrated solar cells at an exhibition (…) and Germany is seen as the world leader in roof integrated solar cells." (Jacobsson/Lauber 2006: 268)

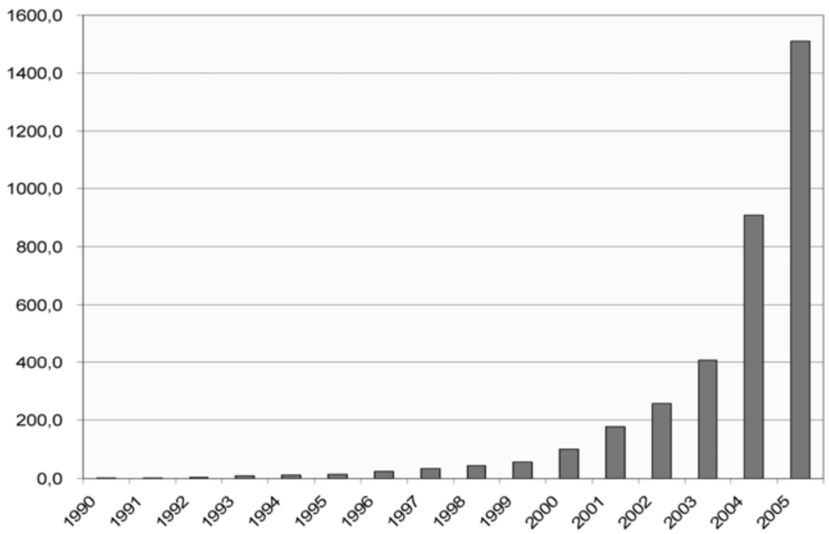
Especially the German machine building industry has benefited from the emergence of photovoltaics. Likewise German solar producers took advantage of the expertise of the machine building industry, since, as mentioned above, many innovations in photovoltaics are geared to cost reductions in the production processes.

Architects and craftsmen, especially electricians have well adapted to the new technology as a growth option for their businesses and surrounding institutions of vocational education managed to adjust their curricula. Thus well-known bottle-necks that often constrain the diffusion of new technologies have been overcome.

A new coalition

The specific dynamic of the advocacy coalition can be revealed if we look at the machine building industry. This industry, which cannot be considered to be part of the original energy policy subsystem proper, is strongly supporting the PV coalition. In its early formative stage the coalition exclusively focused on promoting renewable energy technologies. It shared a joint policy core, which aimed at the transformation of the energy sector through substituting nuclear and fossil power plants for renewable energy technologies. Ensuing learning processes helped to develop new policy instruments. Former radical opposition against the traditional energy sector, based on theories and visions highlighting worst case scenarios on the one hand and demonstrations and blockade actions on the other hand, gave way to more pragmatic considerations and helped the coalition to gain political power. The new PV policy core is now characterised not as pure opposition, but as supporting PV. Its formation has been accompanied by new theories, visions and ideas on generating demand for PV by reducing costs, increasing returns, spreading information and eventually on finding ways to enlarge the coalition. As a result the machine building industry could be integrated into the coalition. Even some utilities, which either do not belong to the policy subsystem or explicitly share another policy core became affiliated to the coalition. Thus, the policy changes towards a concentration on positive support of PV prepared the ground for the inte-

Figure 1: PV power installed in Germany (MWp)



gration of a heterogeneous set of allies.

4.3 Success Indicators

The success story can be further illustrated by providing some quantitative indicators. In order to measure 'success' we will use the indicators 'installed PV power', 'production', 'export sales', 'employees' and 'patents'.

As figure 1 impressively shows, installed PV power was on a relatively low level, then doubled for the first time in 2000 and has grown continuously since then. These findings demonstrate the correlation between policy instruments that were applied by the federal Red-Green coalition government, the regulatory legal instruments supporting PV, and the expansion of the market.

In 2005 "(…) Germany accounted for more than 93% of the EU 25" (Jäger-Waldau 2006: 75) installations. Stable political and socio-economical conditions do not only convince private households to install photovoltaic power installations, but solid markets also stimulate the investment in new production capacities for solar cells and modules.

As can be seen from figure 2, cell production now amounts to more than 500 MW annually. Sales as well as export shipments of the German photovoltaics industry have been rising at a comparable rate, as it is shown in figure 3 and 4.

Sales figures and numbers of photovoltaics power installed can show the market success of photovoltaics. But even more common to measure innovation are patent data, since "(…) patents provide a uniquely detailed source of information on inventive activity" (cf. OECD 1994: 9). As figure 5 shows, Japan is far ahead in patent applications, followed by the USA and Germany.[5] German patent activities well reflect the global increase of photovoltaics patents from around 500 in the early 1990s up to around 2000 in 2002. The numbers for Germany are not much different from those of the USA, and Germany is far ahead of other industrialized countries, such as its European neighbours. Rather than being a precondition for the further development of PV the data seem to suggest that the economic success of PV spurred hectic activities to protect intellectual property.

Altogether these figures clearly prove the (at least short term) success of the PV industry. It is expanding production in Germany and off shore, it is increasing the export ratio of its production, it is employing ever more people, it is working profitable and it accumulates intellectual capital. Meanwhile more companies are active in this sector and more people working there than in many established economic sectors.

5 A future for photovoltaics?

In the beginning we claimed that the creation of niche markets can be a successful policy instrument in coordinated market economies (hypothesis 1), if a powerful advocacy coalition can be mobilised (hypothesis 2).

Our analysis has shown that the support of PV after 1998 has proved to be successful in establishing a growing, profitable economic activity. The PV industry can produce and sell its products both in Germany and abroad. The story, however, has also proved that the success of such a policy depends on many favourable circumstances. It does not only need broad political and

[5] It is striking that Japan accounts for 74% of all patent applications, but this is mainly due to characteristics of the Japanese patent law system, which makes the process of applying for a patent easier and cheaper than in the USA and Germany. Furthermore, in Japan normally one invention is divided into small elements and for each a patent application is filed (cf. Siemer 2005: 66). Therefore comparing German patent activities with the Japanese would be biasing.

Figure 2: Solar cell production in Germany (Mw)

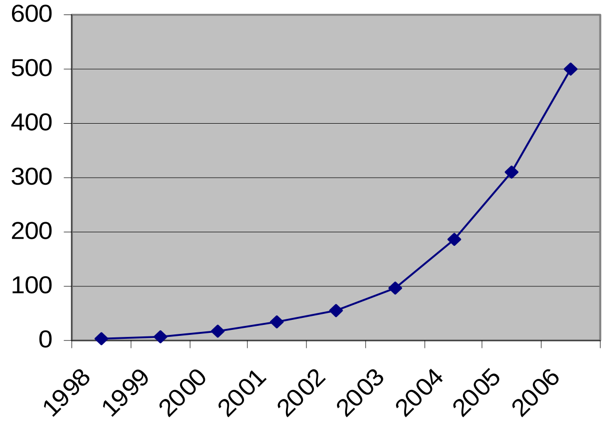


Figure 3: Sales of the German photovoltaics industry (Mio. Euro)

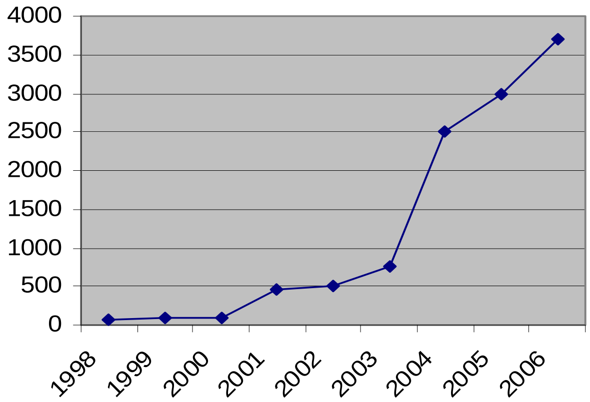


Figure 4: Export sales of the German photovoltaics industry (Mio. Euro)

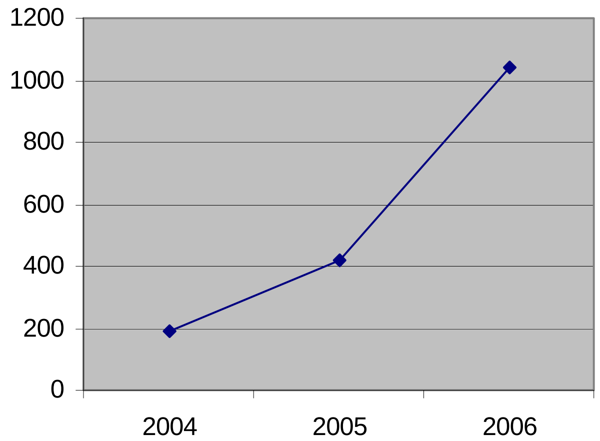
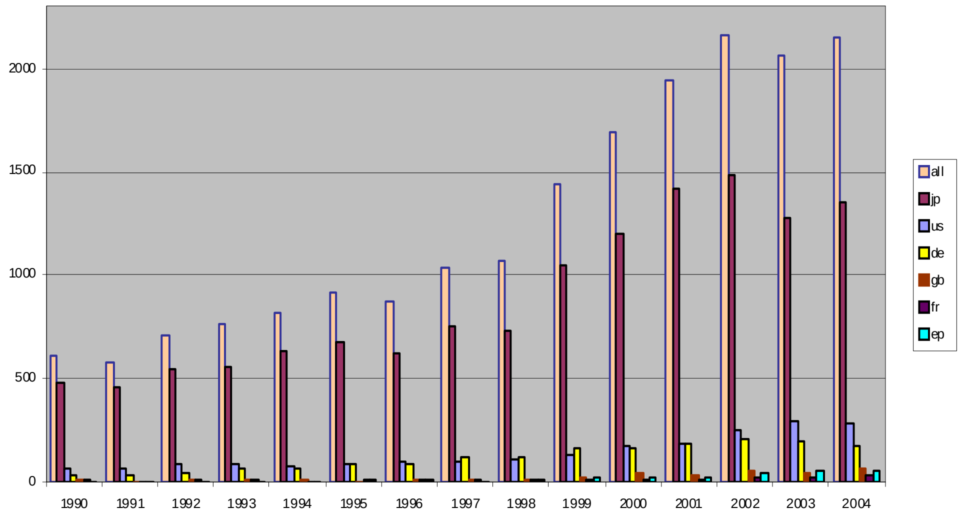


Figure 5: Global patent applications in photovoltaics



public support that goes beyond the initial rather limited policy core, but also a delicate architecture of instruments that are geared towards the special characteristics of the system to be supported. The policy instruments are mostly not generic, but geared towards the specific problems of the PV industry.

The success of PV is also linked to frame conditions, offering a window of opportunity for change. The electric power sector faced new challenges over the last years. These challenges originated in a move to liberalize markets, the expectation that the sector should contribute to environmental aims and the development of new technologies (e.g. renewable energies) each of them apparently hard to cope with by the dominant regime of the sector. PV as an innovative decentralized small technology, which could be connected to the grid without severe difficulties and compatibility problems successfully, exploited the emerging opportunity. PV could rely on existing scientific knowledge in this area and the expertise of suppliers (e.g. machine building industry).

The political instruments developed offered long term security for the industry as well as incentives to build new production units in the disadvantaged regions of the new German *Länder*. The users of PV-modules were guaranteed a 20-year security on their investments. Insofar PV could serve many masters. The present strength of the coalition has only recently been proved when the federal government amended the Renewable Energy Law without implementing important changes. It achieved nearly unanimous support by a public in favour of clean technologies, and it was supported by an advocacy coalition comprising scientists, politicians, environmentalists and increasingly economic actors.

Taken together the many beneficial factors and the very specific composition of the advocacy coalition also point to the difficulties to imitate this successful experiment in other areas. The lesson cannot be that the same policy should be and can be pursued in other cases as well. Rather, the general lesson learned is that customized innovation policies need to reflect the specific conditions and opportunities in the targeted areas.

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Framing Complexity in Financial Markets

An Example of Portfolio Management

Ekaterina Svetlova

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Abstract

Financial markets are complex: Factors that affect their development and the associations between these factors are not clearly assignable. Nevertheless, every day thousands of investors face the task of mastering the complexity of the markets. How do they solve this problem in their daily practice? This paper discusses this question by investigating a special area of the capital markets, namely, portfolio management. Two possible methods of handling the complexity of financial markets are presented: first, the qualitative methods (heuristics), and second, the formal (mostly computer-assisted) models. The central finding of the paper is the high heterogeneity of the applied methods. There are free spaces that portfolio managers can use while framing complex market situations. It could be suggested that this diversity contributes to the emergence and self-preservation of the market complexity. This contribution is dedicated to the empirical argument for these mechanisms.

1 Introduction: Financial Markets Complexity

This article discusses the phenomenon *complexity* as applied to the case of financial markets. Financial markets are often used as an example to illustrate the assertion that the complexity of modern society increased dramatically over last decades. The term *complexity* is thereby applied as a synonym for *uncertainty, lack of control*, or *lack of transparency*. But what exactly is complexity and in what sense are financial markets complex?

Weyer (2009) suggests dividing the existing complexity theories into two groups: Some theories define complexity as an objective structural phenomenon at the macro level; others conceptualize it as a subjective construct. He also points to the fact that theories refer to two dimensions of complexity: quantitative and qualitative.

At the macro level, the quantitative dimension would mean that the complex phenomenon consists of too many components, with too many relations between them; the qualitative dimension indicates that specific interactions between components lead to unpredictable dynamics. Applied to financial markets, this classification would suggest that financial markets are complex because their behavior is determined by several factors that do not show clear associations. It could be easily demonstrated if one suggests that financial market behavior is reflected in asset prices. Asset prices and their trends depend on a large number of factors, whose influence can never be estimated with certainty. In the case of equities, for example, prices depend on the future stream of payments produced by the company, such as earnings and dividends. They are affected by the so-called fundamental factors, e.g., profit situation, product range, market position, and management quality. There are also other factors, such as the macroeconomic conditions (interest rates, inflation, currency developments, etc.), political expectations (tax policies, state subsidies, political stability, etc.), as well as the psychology of the market players (their expectations, risk preferences, etc.). It is not just impossible to specify all variables; rather, it must always be anticipated that new factors are added, such as new products, take-over rumors, etc.[1] A good example is the unexpected insolvency of a local bank in California in February 2007. The unexpected event led to a strong market correction. This example also suggests that small events can have a big influence at the macro level. In general, complex systems are characterized by non-linearity. This means that causes and effects are not proportional; there are back couplings and interdependencies that lead to emergence of unpredictable and chaotic[2] structures (Mainzer 2008, Richter/Rost 2004).

It is important to point out that financial markets' non-linearity and complexity are "man-made". The developments of the securities' prices depend on the behavior of several actors and their interaction in the market: investors, analysts, brokers, companies' executives, and investor relations, to name a few. The participation of different groups and individuals increases the complexity of the system. Those groups and persons are carriers of individual expectations and experiences that must be taken into consideration along with the investors' own expectations. Every player is observed in his or her decision making, while at the same time he is an observer him-

[1] This problem was analyzed by Nassim N. Taleb (2007) in his book "The Black Swan: The Impact of the Highly Improbable." He called the unexpected factors, that influence securities prices significantly, the black swans.

[2] This is the reason why chaos theory is now extensively applied to analyze financial markets. See Trippi (1994) for an overview.

self.[3] In the case of financial markets, Brian Arthur (1995: 3) described this problem as follows: "Where forming expectations means predicting an aggregate outcome that is formed in part from others' expectations, expectation formation can become self-referential." This self-referentiality of expectations, which determine investment prices, is one of the most significant factors that cause complexity of the financial markets.

In the social world, the intentional acting at the level of the individual participants often leads to the "conditions that are essentially the by-products" (Elster 1987: 141). The complex behavior of financial markets is not deducible from the actions of the individual players and is such a by-product. This is why complexity is an immanent feature of financial markets.

However, if we follow the Weyer's classification of complexity theories, the second group of those theories should be mentioned. Representatives of this group (Malik 2002; Schimank 2005) consider complexity as a feature of subjective decision situations. Individuals are limited in their knowledge as well as in their cognitive capacity to process huge volumes of information and to establish causal links between many factors. For example, the market correction due to the insolvency of the Californian bank could not be foreseen by most of the market players, since they had not been aware of the existence of this bank and therefore could not attribute to the event the significance which in the end was attributed to it by the market.

According to Weyer, sociological theory of complexity should consider the entanglement of structural and cognitive factors. In the case of socio-technical systems like aircrafts, for example, it is dissatisfactory to restrict the analysis to the question of how individual cognitive acts are constructed. It is important to reconstruct the design of the system and the room for maneuvering within it (see also Grote 2005).

In this article, I would like to elaborate on the link between the structural and cognitive factors of complexity in the case of financial markets. I will refer to the structure or design of the markets as the market frame and analyze the room for maneuvering that individual investors have within those market frames. Based on empirical research, it can be shown that such room is quite significant. This finding suggests that, though market frames are socially embedded and shared, there are individual ways to reduce complexity within those frames. In other words, complexity reduction at the micro level is itself complex and contributes to the complexity emergence at the macro level.

Those topics will be approached in the article from an empirical perspective: Daily practices of portfolio managers as a specific group of financial market participants will be analyzed. In section 2, the concept of *market frame* will be discussed. In section 3, the distinctive characteristics of portfolio managers will be described. The central question will thus be examining exactly how this group of investors is exposed to the problem of complexity. In section 4, data samples will be presented. Afterwards, two specific ways of dealing with complexity within the field of portfolio management will be outlined: forming heuristics and the use of quantitative models. At the conclusion, all findings will be discussed.

2 Market frames

Social studies of finance have been busy in the last years investigating how different groups of financial mar-

[3] The players are aware of this fact: they include observations and expectations of outside observers into their own hypothesis and expectations. This increases the complexity even further: Luhmann (2002: 181) suggested using the term hyper-complexity for this phenomenon.

ket participants handle the markets' complexity, i.e., how they decide, if there are no "if - then" rules, and if no clear effect can be assigned to any of the factors. According to those studies, there are frames that help to reduce complexity while they "reduce the amount of possible worlds…, that is, reduce contingency" (Arnoldi 2006: 385). Frames limit decision possibilities, focus and structure the information, and help to interpret market events while they define boundaries for perception, meaning, and communication. Complexity is reduced through framing because a structure of possible "if-then" rules emerges.

As an answer to the question "Who constructs the market frame?" Hardie/MacKenzie (2007) suggest the concept of the "distributed framing": "By this we mean the involvement of multiple market actors in the process of sifting data and constructing ways of interpreting it" (Hardie/MacKenzie 2007: 391). This means that frames are formed not entirely individually but in the permanent interaction with other market participants. There are, for example, analysts, brokers, and investors. They develop practices with shared rules, codes, and networks that form frames (Knorr Cetina/Bruegger 2000). It should be added that the state also participates in framing processes by means of legal regulations. Institutional and organizational design is also important. An investor who is a member of a big investment bank has a frame that differs from the frame of a private investor, for example. The first one has the opportunity to receive support services from analysts and brokers or to talk to companies' management because he is an official member of an investment bank. There is also an official funding provided to conduct business trips to visit countries and companies, which means that there is the opportunity to talk to investor relations, companies' CEOs, as well as to state representatives. In other words, access is provided to special sources of information and thus framing possibilities that are inaccessible for private investors. There are also internal rules and rituals within organizations that shape market frames of investors (for example, different official meetings).

It should be also taken into consideration that investment banks employ people who enjoyed similar education at universities or business schools. Institutions also support a specific, business-related training of employees. This leads to the fact that employed investors share basically the same theoretical frames.

Extensive research has also been conducted on the topic of how diffusion of technology and financial formulae influence framing devices of the market participants (Callon 1998, MacKenzie 2001, 2006). In investment institutions, high-power computers as well as specific technical equipment like Bloomberg and Reuters are available (in addition to the telephone and internet).

Social studies of finance demonstrate that there are indeed multiple market actors (brokers, analysts, companies' management, investment organizations, the state, etc.) who participate in the distributed framing. Therefore, social, institutional, and technological conditions are considered to be equally important for framing processes in all types of financial markets: in the foreign exchange market, in the derivatives market, and in the capital market. Studies point to differences between the groups of institutional market participants: derivatives traders (Zaloom 2003, Arnoldi 2006), foreign exchange traders (Knorr Cetina/Bruegger 2000), bond traders (Abolafia 1996), arbitrage traders (Beunza/Stark 2004), as well as securities analysts (Beunza/Garud 2004, Langenohl/Schmidt-Beck 2007). At the same time, they concentrate on similarities of framing devices within those groups.

But if everybody within a particular investors' category is subject to similar constraints and uses the same technology and formulae, one should ask, as do Beunza/Stark (2004), "How can an investor recognize an opportunity?" and "How can he or she profit?". Relating to our topic, we should ask how complexity could be explained in particular financial markets if participants share the frames, i.e., reduce complexity in the same way. In this context, it is important to remember that the standard financial theory that assumes identical investors has difficulties explaining the complex paths financial markets develop, such as bubbles and crashes. How do chaotic structures emerge within different financial markets if actors use homogenous frames to reduce complexity?

The concept of the frame is not sufficient to answer those questions. The focus should be shifted to the room for maneuvering that exists within the frames. The paper at hand discusses the availability and the structure of that flexibility in the case of one additional group of investor professionals that has not previously been the explicit focus of social studies: portfolio managers. Their methods of dealing with complexity will be discussed. It will be demonstrated that although portfolio managers share certain social practices, use similar technologies, and are subject to organizational and institutional constraints, there is still flexibility within those frames. The suggestion of this paper is to take a closer look at flexibility within the frames. The hypothesis is that financial market participants exploit those free spaces in various ways. This means that complexity reduction through framing does not happen uniformly at the micro level. In turn, it is supposed that while portfolio managers exploit free spaces within their frames, they form diverse expectations and make different decisions. This heterogeneity of expectations and decisions as a result of complexity reduction contributes to the increase of complexity in the market. This other side of the coin – an emergence of complexity, not only its reduction – might also be of interest for social studies of finance. Complexity is not a given fact that the market participants find in the market and deal with. Complexity is generated while the market participants handle it in different ways within their frames.

3 Portfolio management

Portfolio managers are financial market professionals who invest the money of their clients in different assets, such as equities, bonds, derivatives and other financial instruments, in order to earn the maximum return for a given risk profile. If the money is provided by an individual client, a portfolio manager assesses the client's individual needs and exercises allocation of funds among assets and particular securities, meaning that the money is not invested in a single stock or bond but in a group of financial instruments, which is called portfolio. A portfolio is a diversified mix of securities. If the money of many investors is pooled in a portfolio, such a portfolio is called a mutual fund. In all cases, the task of a portfolio manager is to decide which and how many securities to buy, as well as to watch and to adjust the portfolio over the course of time.

The process of portfolio construction and adjustment is subject not only to clients' specifications but also to various legal, organizational and institutional constraints. First of all, there are laws that regulate how portfolios can be structured. For example, laws dictate in which securities a portfolio manager can invest at all, how to assure a proper level of diversification in order to protect investors (for example, which percentage of the fund assets is allowed to be invested in a single security), and so on. Portfolio managers are usually employees of investment companies. Investment companies specify the investment products and the investment processes (investment goals, asset classes, reporting period, investment styles, etc.) as well as define how funds' performances will be measured and controlled. For example, if a portfolio manager is responsible for an Emerging Markets Equity Fund, he is allowed to invest only in the equities of particular emerging countries and has to follow a predefined investment process. Therefore, institutions further narrow the operating space of portfolio managers and shape their frames.

Still, within those constraints, a portfolio manager must choose assets that will bring the best return for a given risk profile. Return is the number that relates the final value of an investment to its initial value (in percent). The amount of money at the end of an investment period consists of the yield, like dividends, coupon or interest rate payments, as well as the earnings or losses due to price changes of the security. Those prospective flows of payment and movements of the asset price in the future are uncertain. To compare investment alternatives and to construct a portfolio, portfolio managers have to be able to forecast the returns of those instruments. At this point each portfolio manager faces the complexity problem. As discussed above, due to many unforeseeable factors that influence asset prices and companies' dividends, no reliable rules exist to predict returns and thus to select investments.

But is it not a problem that all financial market professionals face in their everyday practices? One question that may arise regards the specifics of portfolio managers as an investor group and where we should locate them within a broad landscape of social studies of finance. Langenohl/Schmidt-Beck (2007) differentiated two groups of investment professionals. The first group, which consists predominantly of traders, is short-term orientated and acts in the close proximity to the markets; long-term orientated market participants, for example, securities analysts, are not involved in the day-to-day interaction and are concerned with collection and processing of information in order to make investment decisions.

Traders find themselves under pressure to react immediately to the numbers that they observe on the screens. Those numbers are "interpreted not so much as information engendering reflection but more as an imperative to act – that is, to trade" (Langenohl/Schmidt-Beck 2007: 9). Those findings are confirmed by Zaloom (2003: 261): "The immediacy of the market dictates that attention remains on the bid-ask figures that represent the position of the market at that second…Traders can act with little information or understanding of the instrument they trade or the economic conditions of the countries that issue them." Traders have to rely on the immediate real-time market picture provided by the comprehensive technological systems. This means that they do not effectively deal with the future and are not interested in forecasting.

The representatives of the second group analyze economic and companies' data and make forecasts, in order to give recommendations ("buy," "sell," or "hold"), i.e., to communicate forecasts to the other market participants. Analysts do not invest money effectively, i.e., they are not exposed to the market. Their time horizon averages to "several months up to one year" (Langenohl/Schmidt-Beck 2007: 11).

Portfolio managers find themselves between those two poles. However, it should be mentioned that this investor group is not homogenous. By dealing with complexity, i.e., by answering the question about how to forecast returns and how to select securities, portfolio managers use basically two methodologies: fundamental analysis based on processing economic data (companies' financial statements, market position, quality of management, etc.) and quantitative analysis that draws on the mathematical and statistical approaches to assess market movements.

Fundamental portfolio managers are similar in their approach to securities analysts. They not rely only on the permanently changing numbers on the screen but also collect and analyze economic data, perform forecasting, and decide to buy, to sell, or to hold. However, it is important that they must implement their decisions, which means that they enter the market with a particular amount of money. In this sense, portfolio managers are constantly exposed to the markets, like traders.

The frequency of interactions with the market depends, however, on the strategy that portfolio managers follow. There are on the one hand "buy-and-hold" investors who take a long-term view and trade less frequently; there are also short term oriented portfolio managers.

Due to the distinctive nature of their business, portfolio managers face specific challenges and develop specific solutions while dealing with complexity. Those particularities shall be discussed now based on the empirical research.

4 Data

Support for this article is based on research that was conducted in several German and Swiss asset management companies and banks during 2007. The data pool of the analysis encompasses seventeen guided in-depth interviews with financial market professionals. The respondents work as portfolio managers in Frankfurt/Main and in Zurich for major international investment banks (fourteen of the interviewees) and for small investment boutiques (two of them). One interview was conducted with a financial advisor and the owner of an independent investment company. All respondents have more than ten years of experience in their field.

Thirteen interviewees predominantly pursue a fundamentally driven investment strategy. Six of them are responsible for European blue chip portfolios, two for European small and mid-caps, four for emerging markets, and one for investments in bonds. Three interviewed portfolio managers elaborate quantitative strategies to allocate assets and to manage funds.

The duration of the each of the sixteen in-depth interviews was about 60 minutes. Most of the interviews took place in person, and only one was conducted by telephone. All interviews were recorded and transcribed. The evaluation included coding and categorizing (see Corbin/Strauss 2008).

5 Dealing with financial market complexity

The general task of portfolio managers while dealing with complexity consists in establishing "if-then" rules that enable them to forecast asset prices and to construct a portfolio. As mentioned above, there are two general methodologies to do this: fundamental and quantitative. We will discuss separately how complexity reduction at the level of the individual portfolio managers takes place in those two ways. This happens either by applying heuristics (simplified, non-formalized rules of data processing) or by utilizing formal models. In both cases, it can be shown how the "man-made" financial markets' complexity is maintained, while the market players exploit flexibility within their frames.

5.1 Fundamental portfolio management and heuristics

Decisions of portfolio managers – like those of other investor groups - are framed. Those frames are not individual products but are influenced by many social factors. Some of them were already mentioned: there are laws, official rules and processes of the investment company, educational requirements, and technical equipment available within the organization.

Those are frames in which portfolio managers move to reach their goals. Within the frames they develop individual rules to deal with the market complexity, to which the term *heuristics* could be applied: "The term *heuristics* relates to rules or strategies of data processing, which often lead rapidly and at minor costs to a solution that is usually reasonably close to the best possible result, but does not guarantee it: rules of thumb" (Goldberg/von Nitzsch 2004: 49). The most common simplification rules such as mental accounting, anchoring heuristic, and so forth, were described by Kahneman and Tversky in the "Prospect Theory" (1979). In the present paper, the term heuristics is used to designate individual rules and tools for dealing with the financial market complexity, which portfolio managers develop and utilize for their own use. These rules are based on the individual experiences of each market player. Fund managers observe the market and define for themselves the most important factors of influence and causalities. Whenever they have to make decisions, they rely on these same factors of influence and causalities. They also check them continuously and learn from the results (mental back testing).

The interviews with the portfolio managers showed that these simplification rules and tools are quite heterogeneous; i.e., handling the financial market complexity differs substantially from investor to investor and from investment company to investment company. Peter Bernstein (1992) reports on the experience of Jack Treynor, a famous financial theoretician of the 20th century. Treynor was working at the beginning of his career at the foundation of the University of Yale and in the 1960s visited the most important investment organizations in the USA: "He was astonished by the diversity he discovered: No two were doing alike, but every one of them thought they were doing it the right way. This was very perplexing" (Bernstein 1992: 184). Exactly the same picture emerged from the analysis of the interviews with today's portfolio managers: They pursue the goal to predict future prices of securities and arrive at these predictions in completely different ways.

First of all, portfolio managers have room for maneuvering to further limit their investment universe and to reduce the number of securities and factors, about which they are constantly concerned. This is demonstrated in the following interview with a portfolio manager in the bond market (Zurich):

In general, in order to observe my market universe, I use the same data for quite some time. For example, in the US I look at the two-year and the ten-year treasury[4]. I do not look at the five-year and the thirty-year. I could have done this. It sometimes expands a little… the universe, but I try to keep everything the same and clearly arranged.

Question: And the economic data? How do you collect it?

What I do, I always look at the same data… Of course, I have a subjective picture of the priority of the data. For me, for example, the job market numbers in the USA have a high priority. Concerning the inflation… I look at the core CPI[5] and such things. Other people do this a bit differently. Not all people are of the opinion that the job market numbers are important. With the inflation, they look at normal inflation. Or with housing[6]… there I look a little at everything, and then I look at the leading indicators for housing. Then there are some economic data… I do not pay attention to them, I notice them, then I look at "over or

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[4] Government bonds with a maturity of two and ten years.

[5] CPI means consumer price index. It is used as a measure of inflation. Core CPI is a measure of inflation that excludes certain volatile items like food and energy prices.

[6] Housing refers to the monthly number of new residential construction projects and is considered to be a key indicator of economic strength.

under expectations" but I leave them actually aside... and... that way I get my picture.

This interview excerpt clearly shows that this investor pays attention consistently to certain factors, sorts them according to their priority in his own mind, and is aware of the fact that competitors and colleagues consider different criteria.

Portfolio managers also limit the flood of information while they carefully select the sources of information that they use. As mentioned above, available sources of information such as conversations in person or by phone with analysts and brokers, company meetings and press conferences, and meeting with colleagues are elements of frames. However, individual investors attach different importance to them, and, in doing so, define their heuristics. For example, some equity investors believe that regular meetings with the corporate management are crucial for success, while others regard such meetings purely as a waste of time; some rely on the corporate earnings guidance, while others ignore those and concentrate on the assessments of analysts and brokers, with whom they are in touch on a daily basis, either by phone or email. Some investors rely exclusively on external databases and services. Differing significance is also assigned to the information exchange with colleagues. In large investment companies, there is a meeting each morning, an investment meeting each week or month, regular meetings or conference calls with the buy-side analysts. Those different modes of information exchange are regarded by the employees of the organizations either as useful or a waste of time. An interview partner (small and mid-caps, Frankfurt/Main) from a small asset management company reported that there are no formal meetings within his organization: The informal exchange between the colleagues takes place only if necessary; this allegedly saves a lot of time.

The received information is also systematized completely differently. Some portfolio managers simply write memos. Some use "home-made" tools such as Excel spreadsheets that assist them to monitor and evaluate the corporate and market data. Which data are included in those spreadsheets and which key numbers are computed are likewise heuristic: Each portfolio manager decides the matter individually, relying on his own experience. Thus, consensus expectations, expectations built by particular analysts, companies' forecasts as well as actual numbers already published by companies, and the prognoses of the fund managers are utilized as input data for the spreadsheets. Depending upon the individual portfolio manager, calculations include relative key numbers like PE[7], cash flow key numbers, growth rates, etc. According to one interview partner (an independent financial advisor, Frankfurt/Main), even professional investors, who apply the same investment styles (growth or value), calculate different key numbers in their spreadsheets. The regularity of updates also depends on the individual investor: The spreadsheets are updated before or after the meeting with the company management, after the publication of the quarterly reports, after ad-hoc news, etc.

To evaluate the companies and to make investment decisions, some fund managers use informal, individually designed scoring models, in which the fundamental quality and valuation of an enterprise are given a score. The final score is used as a base for an investment decision. This approach is applied systematically; however, the assignment of the scores is not subject to any systematization or calculation, but rather to a purely subjective judgment.

Each portfolio manager tries to generate a picture of the market or of a

[7] PE is the relation of the price to the earnings and is used as a valuation tool.

company based upon his own individual rules and tools. These tools must be "comfortable" and fit into the manager's own philosophy. The following fund manager's statement can be considered as representative:

With the help of my spreadsheets, I produce an image of the company in my head: whether the firm grows, how it grows - in "doubles digits" or "single digits", organically or otherwise. For me, such pictures are important to determine the trend. This is my way of thinking. (Fund manager, European emerging markets, Frankfurt/Main)

In the interviews, the portfolio managers often refer to a picture of the market or of a company as a puzzle, which develops during the course of applying the heuristic rules and tools. The heterogeneity of the approaches in handling complexity leads necessarily to the diversity of these puzzles' pictures and thus to the diversity of the expectations and decisions that are based on them.

However, it seems that diversity of individual approaches is desirable for investment companies. Beunza/Stark (2004: 395) demonstrated in their paper that in the case of arbitrage traders, the trading room is organized in the way that diversity of calculations is maintained; uniformity is not welcomed. Interviews with portfolio managers show as well that different approaches are used within the same banking house or asset management company. Two portfolio managers, who are active in the same investment company but at different branch offices in Zurich and in Frankfurt, reported on two completely different investment processes. In Zurich, the process is strongly formalized, it is a team- and model-based investment process; in Frankfurt, each portfolio manager is completely free in designing his own investment strategy. Some investment companies knowingly allow the heterogeneity of the approaches. For example, the portfolio manager of Jupiter's Global Managed Fund, who has nine other managers in his team, stated: "I encourage each of the managers to do their own thing, to run their fund in the way they want to run it" (Kelleher 2007: 11).

Now we have a picture of portfolio managers who reduce complexity non-uniformly. They use available elements of their framing devices and combine them differently. The tightness of the free space is highly determined by the organizational rules, but such free space always exists.

This picture is applicable because the asset management industry is still a highly individual business. It relies on the experts, the individual portfolio managers, who supposedly earn over years a better profit than the market average or the competition. The investment companies rely on the individuals, "the gold fingers" (Döhle/Hetzer/Palan 2002: 154-164). At the same time, however, the weaknesses of those key players are becoming ever more apparent to the industry: Lacking discipline, possessing limited capacities in data processing, and depending on emotion jeopardize the performance of the active fund managers. The solution is expected from the consistent application of the computerized strategies.

5.2 Formal Models

An alternative method to deal with the complexity in the market is the use of formalized, computer-assisted models. The associations between the factors of influence and their effects are determined with the help of statistical procedures. Computers analyze past data and determine which factors, under what type of conditions, were significant for the outperformance of certain securities. These analyses then serve to predict what factors will be significant in the future. As in the case of heuristics, the number of factors to be considered is deliberately limited, and the associations between those factors are ascertained. The computerized strategies of the complexity reduction are, however, not based on human experience, but rather on the statistic analyses.

Quantitative models are elements of the portfolio managers' frames. They are often relatively similar to each other. A portfolio manager (quantitative asset allocation, Zurich) described the formalized tools that are used in her bank as follows:

> We have valuation… What we naturally also have, is momentum, we have sentiment and cyclical forces.[8] It is exactly alike in every other asset management shop.

One of the reasons for the models' similarity is the fact that the experts, who program and use quantitative tools, are trained at the universities in the same mathematical methods. In addition, the successful strategies are rather quickly imitated (Gangahar 2007: 7). Quantitative portfolio managers observe each other's products and adopt and modify some of them. One quantitative expert, introducing tools developed in his division, used the word "steal" several times: "We stole this model from this and this bank," and it seems to be a common practice.

Given this tendency, the question arises about whether the application of the computer models can reduce the market complexity to such an extent that the markets could no longer be maintained. Here we are addressing the problem of "computer herding": If the investors judge the market with the same or similar formal models, i.e., reduce the complexity in the same way, they will also have the same or similar expectations and make the same decisions. This means that all of them would favor the same side of the market. In other words, they would want only to buy at the same time or only to sell at the same time. This would cause the other side of the market to thin out and threaten the market's existence.

For example, the implementation of similar stop-loss strategies for the computer-controlled portfolio insurances was one of the factors that caused the stock market crisis in 1987 (see Authers 2007: 9). In August 2007, the unfavorable developments of some qualitatively managed hedge funds caused similar turbulences in the market. A global quantitative equity fund of Goldman Sachs lost 30 per cent of its value within one week because the computers could not foresee some market movements and as a result implemented a wrong strategy. Many other computer-managed investment funds experienced the same fate and caused the drastic price fall in the market (Tett/Gangahar 2007: 7).

With this in mind, we must raise the question of whether complexity is reduced in the field of the quantitative portfolio management nearly uniformly, within the very tight frames.

Currently, we cannot assert that. Since each investment company and each portfolio manager still develop their own models, the models are not absolutely identical. The diversity is also caused by the fact that all preliminary modeling decisions are made by humans. During the process of "crafting" the models,[9] the experts determine individually which data sources are utilized, which data are collected and processed, as well as how individual parameters are modeled.

In addition, many portfolio managers are still convinced of the fact that numerous important parameters are not quantifiable. The fund advisor Nils Bartram from Hauck & Aufhäuser commented: "There are soft factors, which are very important for the future share

[8] Valuation, momentum, and sentiment are techniques to assess securities and markets. Valuation helps to estimate the market value of an asset and to decide if it is expensive or cheap. Momentum refers to the dynamics of price movements. Sentiment indicators gauge investor attitudes toward the market. Cyclical forces refer to the influence of the general business cycle.

[9] Several interviewees termed the process of modeling as "crafting" the models.

development, which you cannot press into any Excel tables" (Hussla 2007: 26). The qualitative factors (the management quality, the value of a brand, corporate governance, etc.) are taken into consideration only in the form of subjective estimations. This subjectivity causes inaccuracy. A portfolio manager (European emerging markets, Zurich) describes the problems of the application of a formal valuation model:

> Our funds performed badly in the last year because input data for the models are mere subjective estimations. During the last year, we assessed the growth of the Chinese market too low; accordingly we estimated the oil price at around 33 USD (we are maintaining this forecast still[10]). That led to the fact that the macro data, which were fed into the model, were wrong; everything was wrong then. Garbage in - garbage out. That is our central problem with models.

The leeway, which exists when "feeding" the models, leads to heterogeneous statements and decisions and prevents a radical complexity reduction in the market.

Flexibility often exists also during the implementation of the computer-based strategies. The extent of the flexibility depends particularly on the policy of the investment companies; i.e., an institution decides again how tight frames are. Some insist on the radical implementation of the strategies handled by the computers because only in this way can the advantages of the qualitative investment be completely exhausted.

However, some investment companies allow the last decision to be made by humans. They permit the fund managers to bring in their experiences and their feelings for the market and to implement the models' recommendations or not Portfolio managers term this procedure a "qualitative overlay." One of them (tactical asset allocation, Zurich) describes it as follows:

> In the end, the whole is, to be honest, a qualitative decision. We decide how serious we take the valuation signal, for example. It is an overlay when we say "OK, the yen is, according to the purchasing-power parity model, strongly undervalued, but the macroeconomic parameters don't look good…it is unlikely, that the Bank of Japan increase the interest rates, and so on." For this reason we don't take a strong position in yen. It is a typical decision. Very qualitative.

The interviews confirm that creative intuition, interpretations, story telling, metaphors, and fantasies principally supplement formal methods of handling and thus maintaining the complexity in the markets. The portfolio managers still do not trust the formal methods entirely and use them only as supporting tools for their decisions. In general, the flexibility in implementing the models' strategies is considered as a central condition of their application. Here is an example:

> It is important to know, what is going on in a company. If a model recommends buying a cheap company, I must know why it is cheap. For example, Surgut[11] is cheap, it has been cheap for a long time, but the reason for this is known: its management. Prosperity fund (a large shareholder) plans a management change within the company. If that finally happens, if the previous managers are fired and a new team is hired, the Surgut will double, and it will be a good deal. Until then it remains uninteresting, no matter how cheap it is. (Fund manager, European emerging markets, Frankfurt/Main)

The head of the "Quantitative Strategies and Risk Research" department in a big investment house in Frankfurt/Main described three generally possible handling of model outcomes:

> We have three basic approaches… First of all, we have a strong research supply for all fund managers; they can access this research freely and without restrictions, but they are not obliged (that's an important point!). Then there is overlay advisory. For example, we have a signal… equity market or bond market short-long (we keep it simple), then we have a portfolio manager who has a broad bond fund and who says,

[10] March 2007.

[11] Surgutneftegaz is one of the major listed oil and gas companies in Russia.

"The model which signals short-long is a good model." He receives then an e-mail from us whenever we have a new signal and implements it 1:1. The next stage is that we work with model portfolios. It is usually the case when we have an investment process where we say, "The first step is the quantitative approach," for example screening over many equities… we prepare the list of hundred most interesting equities and allocate the model portfolio. In the first stage of the investment process there is this input, in the second stage the fund manager checks, "Does the whole thing fit?" … he adjusts the whole thing, makes an explicit overlay… We distinguish it internally: it is a model portfolio if concrete weightings are assigned; it is a pure research if it is just a list, a ranking.

The interview shows that there are three ways to handle the results of quantitative departments within one investment company. The free space of portfolio managers depends on the product that they manage and on the company's strategy. But if there are no clear instructions to use a model, the personal opinion about models ("the model is a good model") is crucial. In other words, models are a part of frames, but they do not always have to be used.

The existence of the qualitative overlay suggests that skepticism about the usefulness of formal models often prevails. Generally, it is argued: "There are many useful areas for investment judgment where quantitative models never become practicable. In 1996, what did investors say would be the impact on Hong Kong stock values when that British colony reverts to mainland China in 1997? There are simply not enough cases of very similar type to do a least-square regression of returns versus possible governing factors. One may do better by forming a subjective judgment, reasoning from cases that are similar enough to offer analogy, but that are not similar enough to use for statistical analysis" (Wilcox 1997: 66). In other words, there are always new factors added, which are not considered in any model and which must be programmed afterwards. In the interviews, the subprime crisis was mentioned as such a factor. A portfolio manager (tactical asset allocation, Zurich) reported that she just started to integrate this new factor into her models in December 2007, when the crisis was already in full swing. She described the inclusion of the new factor as a creative process, which her competitors perhaps arrange similarly, but differently, so that their models generate a different output.

Models prove to be highly imperfect instruments for handling complexity because they are not capable of capturing all relevant factors and determining causal relations between them. Models cannot supply clear forecasts because they cannot sufficiently take into consideration the dynamics of the relevant factors, particularly their changes as well as the emergence of new factors. An interview partner (bond portfolio manager, Zurich) reported on his experience with an interest rate model:

Years ago I also created some models: regression and factor models and so on. Those functioned very well for some time, for about two years, but then there were shocks. For example, the Asia crisis, the Emerging Markets crisis and LTCM[12], also the Russian default[13]. In any case, everything went completely wrong. The model said six percent, and the interest rate was four percent. Previously the difference had been in the range of 20-30 basis points; thus, it had been correct. Nevertheless, all of a sudden, nothing could be done with it. In the original format that I had conceptualized, the model was no longer useful. The dominant factor in the market became "the escape into the quality"; the bonds rose, the equity fell due to this one particular factor. And this factor was not included into the model. If I had taken in my model the variable "Emerging Markets Spreads," then it would have functioned very well. However, that was originally not included.

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[12] LTCM: A large hedge fund that put the global financial system at risk as a result of its collapse in 1998.

[13] Russian default: Financial crisis in Russia, which led to the suspension of debt payment of the Russian state in 1998

The relations between the market-relevant factors cannot clearly be determined for a sufficiently long period. As William Strazzullo, the Chief Market Strategist at Bell Curve Trading, put it: "When they [models] work, it's good, but over time relationships [between the factors included in the model] inevitably break down" (Gangahar 2007: 7). Complexity is reduced by the application of the models only temporarily and rather seemingly.

Handling the models is an additional complexity factor in the financial market and represents a fundamental problem for all model users. A uniform model determining the different market parameters does not exist. A portfolio manager (quantitative asset allocation, Zurich) reported that she runs several models simultaneously, in order to compute parameters such as momentum or sentiment; each of the models, estimating the same parameter, can produce different recommendations. As a result, the problem of the model combination develops: How does one deal with the different recommendations of the models that determine the same parameters? Today's market players consider this as a central problem:

> This is something where investment managers really differ. Because the tools are always the same: a little of DCF[14] or, my God, do I take the equilibrium interest rate or the latest short term … oh, that is trivial: we look at it, we know the outcome. The question is: How does the model combination work? And this is what makes the shops different (quantitative asset allocation, Zurich).

Model combination is a problem, which develops the market complexity in the process of the quantitative handling. Portfolio managers, who use formal computer-assisted methods, must judge how they include the quantitative parameters in their decision-making processes, while those parameters are differently determined by computers. Hence, they are confronted with another complex problem, which again can be solved either with the help of heuristics (subjective judgment) or with formal methods of model combination (model mixing, model synthesis, model switching, etc.). In other words, the market participants treat the problem of the model combination, like all other market problems, in different ways. This guarantees the heterogeneity of expectations and decisions in the market and at the same time produces additional complexity. Financial market complexity remains "man-made."

In addition, the models themselves must be considered as a complexity factor. They become a factor of influence because their interaction, as already suggested, affects the market. Problems like "computer herding" and "model combination" give evidence that the application of models increases the complexity in the markets rather than drastically decreasing it. With MacKenzie (2006), it can be assumed here that financial models are not "recording equipment" (cameras), but also "engines," which became an independent and substantial part of the economic processes. Thus, if models evaluate markets and compute the investment strategies, they have to include themselves as a factor of influence in their calculations. However, this is what they cannot do, meaning that they cannot record and capture the total complexity of the markets. Their use provokes the diversity of decisions and results in an increase of the market complexity.

6 Conclusion

In this paper, it has been shown that, though the practice of portfolio managers is tightly framed by law, financial institutions, education, and technological tools, there is room for portfolio managers to use those frames independently and non-uniformly. We

[14] DCF refers to the Discounted Cash Flow model: Valuation tool based on estimated future cash Flows.

demonstrated the flexible use of those rooms by discussing both ways of the complexity reduction at the individual level: heuristics and formal models.

The application of heuristics, i.e., the individual rules and tools of data processing, leads to the diversity of the investors' approaches. Investors either choose which elements of the frame (analysts' reports, management meetings, communication with colleagues) they effectively use, or they create their own tools like individual spreadsheets or scoring models within the given frames. Heuristics vary very strongly.

Though complicated formal tools, which are based on the mathematical models, show a tendency to standardization, we also find here significant flexibility in their usage. Models are not uniformly conceptualized and "fed"; their results are often subject to interpretation and discussion ("qualitative overlay"). The existence of room for maneuvering in utilizing formal models is considered by market participants as a necessary condition for the use of models at all. Formal tools also produce problems, for example, model combination, which requires individual creative solutions within existing frames.

In other words, there are heterogeneous ways of complexity reduction within frames. Financial market complexity is thus not a result of the interplay of identical actors with straightforward frames that are uniformly used. This finding is important because it draws attention to the question of the complexity emergence. It could be suggested that the discovered diversity contributes to the emergence and maintenance of market complexity at the macro level. Financial market complexity is caused not just by reciprocity of actors who are primitive and comprehensible in their way (like Brownian particles). There is also complexity at the micro level that has to be taken into consideration. Attention should be paid to the question of how complexity in the financial markets is generated, as each individual participant tries to reduce it.

There are already inquiries of this kind in the economic theory of complexity. Arthur et al. (1996) showed, for example, by means of computer simulations, that if we assume heterogeneous financial market participants and their interdependence and let them adopt their beliefs quickly, then "the market self-organizes into a complex regime" (Arthur et al, 1996: 4). Bubbles and crashes occur, and prices show complex statistical features. This mechanism should be explored more closely from the sociological point of view.

Interviews are obviously an insufficient tool to deal with this problem. Participant observations and further methods of empirical research are required. But this coupling between heterogeneity of individual ways of handling complexity and the emergence of complexity at the macro level should be considered as the next step of research.

7 References

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