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DDT and the Dynamics of Risk Knowledge Production

Stefan Böschen*

Abstract: Until today, the sociological analysis of risky technologies has moved between the two poles of risk constructivism and risk objectivism. A historical analysis of the evolution of risk knowledge may help clarify the issue. I argue that risk hypotheses can acquire the status of a fact in the course of risk debates. In this way, they are equipped with a certain 'robustness' and become guidance for action. As a case in point, I analyse the evolution of risk knowledge resources in the debate on DDT.

Keywords: *sociology of risk research, case study on DDT, research programs.*

Introduction

Chemistry is undoubtedly one of the most important sciences, with an enormous social significance. Many of its processes and products have impact on our everyday life. This can be demonstrated most clearly by the case of a single substance, DDT. The public image of DDT has changed dramatically. In the beginning, DDT was looked upon as a wonder chemical of World War II. Afterwards, it fell into disrepute, especially as it was considered as one of the causes of an imminent *Silent Spring* (Rachel Carson). Finally, in the early 1970s, the use of DDT was prohibited for most of its previous purposes such as in agriculture. Failure followed success very closely. It is intriguing to search for the point when the image of success was superseded by the image of failure.[1] Therefore, I suggest a sociological perspective, which in the case of DDT, but not limited to that, analyses the process of knowledge production and the establishment of risk perspectives.

One of the roots of the sociological analysis of risks is the critique of an objectivist notion of risk (Krohn & Krücken 1993). But until today, this branch of sociology has moved between the two poles of a social constructivist and an objectivist notion of risk.[2] Acknowledging this tension, it seems to be fruitful to analyze the generation and stabilization if risk knowledge in historical case studies. My starting point is the assumption that risk hypotheses can acquire the status of a fact in the course of risk debates. They are equipped with a certain 'robustness' and become guidance for action.

Research in this area need not start from the beginning but can draw upon findings in the philosophy of science. The methodology of research programs (Lakatos 1970; Inhetveen & Kötter 1994) was a landmark in the debate about the evolution of scientific knowledge and was therefore applied to other fields of knowledge production, especially to the evolution of technological processes (*e.g.*, Dosi 1982). In this context, the starting point is an innovative idea or design that has proved its innovative potential in principle by providing a prototype. The innovative idea is then further elaborated to become an innovation in a complex social process, influenced by many different factors. Dosi calls the way of the social construction of technologies *trajectories*. The reconstruction of technological research programs puts the main emphasis on contextual factors and, thus, broadens the meaning of 'research program'.

It seems to be obvious that this kind of analysis provides an interesting heuristics for the study of risk knowledge production. The starting point is then an innovative risk hypothesis or a set of risk hypotheses which are elaborated (or not) in a complex social process of knowledge production and decision making. The main hypothesis of my argumentation is therefore that the history of risk research can be described as the evolution (or nonevolution) of risk research programs along in a path, so that a *risk constellation* develops (by analogy with the *trajectory* in the case of technological programs). I define 'risk constellation' as the set of circumstances (*e.g.*, institutional, cognitive, and normative factors) that affect the generation (or nongeneration) of risk knowledge as well as the acceptance (or rejection) of that knowledge as a guidance for action.

The production of risk knowledge differs from the disciplinary knowledge production in one very important point. In 'normal science' (Kuhn) a scientific community defines its problems in an autonomous way aligned with the scientific standards of this discipline. In the case of risk knowledge production, however, there is not only a scientific community that defines the problems, but also other social forces with their own value frames. Therefore, not only epistemic values but also social and political ones are brought to bear upon this process. When scientific knowledge meets policy, 'problem-centered communities' (Böschen 2000, p. 323) emerge. A problem-centered community is a network of actors that defines and regulates a particular set of problems and that is balanced by the tension between knowledge and hierarchy. Such a network is relatively closed if the integration of the community is organized by hierarchy, and relatively open if that is organized through knowledge. In the former case, the social structure of the community can persist even if the problems change and individuals are exchanged.

My case study is structured as follows. In Section 1, I briefly survey the situation before the introduction of DDT in agriculture. This allows discussing two different options of fighting against insect pests in agriculture, chemical and biological-ecological pest control. These two projects illustrate two completely different types of creating an agricultural landscape. Gradually, chemical pest control, based on the use of lead arsenates as pesticides, superseded the biological-ecological one. Therefore, the situation was well prepared for the introduction of DDT and its use in huge quantities. In Section 2, I treat the downside of the industrialization of agriculture, the risks of using pesticides. While the lead arsenates were being introduced and widely applied, different types of risk were discussed. Apart from the discourse about actual damage, the discourse about potential damage gained acceptance. Both preformed the debate over the risks of DDT. In Section 3, I discuss the explosive dynamics of the risk debate. Many different risk hypotheses were advanced and the problem-centered community expanded, but remained closed for the public. In Section 4, I briefly describe the phasing-out of DDT after the publication of *Silent Spring*. Finally, I discuss some aspects of the evolution of the risk constellation in this case.

1. Two types of agriculture

First, we have to recognize the structure of the technological field in which pesticides where used, agriculture. With the beginning of the industrialization, there were also ideas of an industrialization of agriculture because the demand for food was rising. The first step was the introduction of fertilizers in mid-19th century after Liebig had worked out the connection between plant growth and its limitation by the availability of nitrogen. The second generation of his nitrogen fertilizer was a great success. The next step was the introduction of chemical pesticides at the end of the 19th century.[3]

The agriculture in the U.S.A. was dominated by large technical visions in the 1920s and 1930s. Increasing competition among farmers, who had to manage their farms economically, promoted confidence in the chemical pest-control system and the related vision of technological success. Chemicals were widely available for different field situations. At the same time, there were only few biological-ecological pest control systems for certain purposes, and they were difficult to implement because they required extensive collaboration of the farmers. "The failures of other methods to meet public demands for ways to stop insects without long, expensive research, changes in farm practices, or long-term planning paved the way for chemicals" (Dunlap 1981, p. 35). From about 1910 onwards, there was a concentration on the chemical project of insect control and a concomitant loss of competence in the area of biological-ecological approaches. The most important differences between the two types of pest control systems are displayed in Table 1.

The preoccupation of the farmers was shared and supported by the activities of the Bureau of Entomology and Plant Quarantine (BEPQ) of the United States Department of Agriculture (USDA). Since the Entomological Commission had been formed and established as a Bureau (1878), the Economic Entomologists had to fight for their reputation for many decades. By the 1920s they shed their image as the "unscientific dabblers of the farmer class" (Whitaker 1974, p. 31) and developed to a reputable scientific community with their own standards and publications (*Journal of Economic Entomology*). Apart from the development of the chemical insect control system, there were also the first regulation activities at the USDA resulting in the Pure Food and Drug Act (PFDA, 1906) and the Federal Insecticide Act (FIA, 1910).[4] With the foundation of the Bureau of Chemistry, the two areas of regulation (with their diverging interests) were combined in one regulatory unit. Conflicts seemed to be unavoidable.

Attributes and demands	**Different projects of insect control**	
	Chemical pest control system	**Biological-ecological pest control system**
Availability	*Large, in various agricultural situations*	*Small, only in some agricultural situations*
Scientific foundation	*Large empirical base, many studies on chemical efficacy*	*Small empirical base, many uncertainties within the theoretical framework of ecology*
Relation to the natural environment	*Narrow point of view, ignoring different ecological contexts, 'fight against nature'*	*Focus on different aspects of the environment and using these insights*
Social implementation	*Easy, meets ideas of individualism and competition.*	*Difficult, implementation requires cooperation of different users*

Table 1: Two types of pest control system and their main differences

2. Discourses about the risks of pesticides

The benefits of the chemicals were connected with relevant risks. James Whorton noted in his history of the pre-DDT phase: "Chemical insecticides were developed to meet a pressing, legitimate need; they were developed at a time when danger of epidemic chronic intoxication from environmental contaminants could not be fully appreciated" (Whorton 1974, p. XII). However, what kind of risks was recognized in this era?

In the first years of using chemical insecticides in agriculture, the risks were fundamentally risks of production. Arsenicals are very acute toxins. This is why their application was a health hazard for the farmers themselves. However, the debates about industrial hygiene in the late 19th century had resulted in the formation of instruments that were suitable to deal with these problems. Drawing on these experiences, a *discourse on actual damage* arose in this period.[5] The discourse was well established at the beginning of the 20th century and was the point of reference for later debates. It was only in the late 1920s that scientists discussed the risks of spray residues on fruits and vegetables. That debate had two peculiarities. First, it focused on the risk for consumers and, second, the damage was not as obvious as in the case of acute toxicological phenomena. Thus, a *discourse on potential damage* was initiated. My aim is to analyze the development of this discourse.

The driving force of the debate was a problem of trade at first. Great Britain regulated the spray residues by imposing a lower threshold[6] than the U.S., so that farmers could not sell their products to Great Britain due to an import embargo. The Secretary of State for Agriculture, William Jardine, installed a commission of toxicologists and physiologists (from universities and the public administration) to recommend thresholds for arsenicals and lead. Apparently, the Hunt Commission took notice of the possibility of chronic effects: "[…] the insidious character of accumulative poisoning is known to be easily overlooked and […] the lack of evidence of prevalence of such poisoning must not be accepted as proof that such poisoning does not exist" (quoted from Whorton 1974, p. 186). This is very remarkable, because a new focus of the spray residue problem was opened up, the problem of possible chronic effects on consumers.

The physiologist Anton Carlson was the first to direct the attention of a broader public to the problem of accumulative poisoning effects of lead and arsenate. In an article in the eminent scientific journal *Science*, he submitted that "we may not inhale enough lead on our breathing or consume enough lead and arsenate in our fruit to produce acute poisoning and tissue injury, but who is there to say that this slow assimilation of metallic poisons brought about by modern industry is without danger and ultimate injury" (Carlson 1928, p. 357). In the following period, an enormous number of studies on the chronic and accumulative aspects of the spray residues of lead and arsenate were carried out. More and more physicians looked at this field of experience, *e.g.* Myers and Throne, from the New York Skin and Cancer Hospital, with their studies on lead and arsenate-induced diseases. They argued that insecticides play an important role as "[…] a distinct menace to our well-being, and unless discontinued will lead to a marked menace in diseases of obscure nature, such as eczema, keratosis, peripheral neuritis, disturbances of vision, and neurological symptoms hitherto obscure" (Myers *et al.* 1933, p. 625). With regard to these insights, the Food and Drug Administration (FDA) had to deal with certain regulatory problems, because action was only possible at a moment of proven damage to human well-being (White 1933, p. 623).

The FDA was founded in 1927, when the old Bureau of Chemistry in the USDA was reformed. By this reorganization on the level of Bureaus, the USDA wanted to channel the conflicts of interest between the insecticide industry and farmers lobby on the one hand and the interests of the consumers on the other. The FDA was responsible only for regulations concerning the Pure Food and Drug Act – therefore the spray residue problem was one of the firsts to be solved by the FDA. Paul Dunbar, later vice president of the FDA, wrote: "Soon after it began operations, the Food and Drug Administration became involved in the spray-residue project, an activity which in varying phases claimed major attention throughout the ensuing years. (...) The project was loaded with political dynamite" (Dunbar 1959, p. 128). Therefore, the FDA attracted a lot of public attention in its first years. However, people did not really discuss the spray-residue problem before the beginning of the New Deal.

During this time, the formation of a *problem-centered community* began. This type of community augmented the ‘scientific communities’ in the context of risk debates by including political and decision-related aspects. Typically, a problem-centered community emerges to analyze the different unexpected side effects arising from the evolution of technology and systems. The debates in these social places are necessary to the development of problem-solving capacities (*e.g.*, to fix thresholds) and are oriented towards certain aims of protection. They are scientific debates that accompany regulation processes. Thus, it is not surprising that the administration frequently instigates important initiatives that are then elaborated in its regulatory units (see Böschen 2000, p. 323). The problem-centered community 'Pesticide Regulation' was confronted with a particular conflict of interest between the fruit farmers, their lobby in the Congress, and the USDA on the one hand and the FDA and some physicians on the other. Furthermore, and for the first time in history, there was a great public interest in a scientific and regulatory debate (Jackson 1970, p. 108). Finally, there was a reform of the legislative foundations by the Food, Drug and Cosmetic Act (FDCA) in 1938.

However, the differences of opinion between the FDA and the Bureau of Chemistry and other regulatory units continued. With the FDCA, the FDA was authorized to set standards for the various chemicals, but the tests for fixing thresholds were carried out by the Public Health Service (PHS). In 1940, the Federal Security Administration was founded with both bureaus, the FDA and the PHS, under its regime. The old conflicts between the Bureau of Chemistry and the FDA were settled, but new ones were at the horizon because the two bureaus used incommensurable methods of risk research.

In the problem-centered community, the conflict between the different methods became more severe and culminated in the confrontation between the two discourses and their aligning value settings: the discourse on actual damage on the one hand and the discourse on potential damage on the other. PHS preferred the first discourse, the FDA the second one. Therefore, the designs of their studies were very different. "PHS investigations differed radically from those of the FDA. Instead of working primarily with experimental animals under laboratory conditions, PHS sent its scientists to make a study 'of the working environment with regard to insecticidal sprays and its effects upon health in the apple districts in the State of Washington'" (Whitaker 1974, p. 364). The PHS looked at a certain population of farmers and consumers in fruit growing landscapes. They analyzed clinical data for dose-response-relationships. This research frame was that of the occupational medicine. Although there was a significant increase of lead arsenate in the blood of this population, there were no obvious signs of a health hazard. This strategy was orientated only towards the discourse on concrete damage with focus on the protection of the farmers. The FDA analyzed laboratory animals for the physiological effects due to the lead arsenates. Their research goal was to elaborate a description of the chronic intoxication – a potential public health hazard. Therefore, this discourse was mainly orientated towards the protection of the consumers. In the debates of that time, the discourse on actual damage was the most influential, because it seemed to provide a solid base for judgements. In addition, it had a social base, because the USDA, the industry and the farmers and their lobby built up an 'iron triangle' (Bosso 1987) to protect their interests.

3. The introduction of DDT and the explosive dynamics in the risk discourse about DDT

First synthesized and described in 1874, DDT was developed as insecticide in 1939 by Paul Müller of the Swiss Chemical Plant J.R. Geigy AG. Because of the high toxic effects on insects and the negligible acute toxic effects on humans, the chemical promised to have a broad range of applications. Among the studies by the PHS that showed the negligible acute toxic effects (Neal *et al.* 1944) there were some early indications of a possible health hazard of DDT due to its chronic toxic effects. But it was wartime and the military forces had an urgent need for this kind of chemicals because of enormous losses of soldiers caused by tropical diseases. In a speech in Parliament (House of Commons), Winston Churchill said: "We have discovered many preventives against tropical diseases, and often against the onslaught of insects of all kinds, from lice to mosquitoes and back again. The excellent DDT powder, which has been fully experimented with and found to yield astonishing results, will henceforth be used on a great scale by British forces in Burma and the American and Australian forces in the Pacific and India in all theatres

(...)" (quoted from West & Campbell 1950, p. 11). The usefulness of the insecticide was also seen in the winter 1943/44 during the typhoid epidemic in Naples. DDT was not only a weapon that helped the Allied Forces to win the war; it also inflamed the farmers and their lobby with enormous expectation. After the war, the war seemed to be continued as a war against insects. On August 1, 1945, DDT was delivered for nonmilitary use. Soon DDT was a big business, because every chemical firm wanted the rights for producing this wonder chemical. It was said: "The publicity given DDT might well be envied by any Hollywood movie actor" (Brittin 1950, p. 594). Yet, two scientists from the U.S. Fish and Wildlife Service stated, "From the beginning of its wartime use the potency of DDT has been the cause of both enthusiasm and grave concern" (Cottam & Higgins 1946, p. 44). By the time, insights into possible harmful effects grew and the debates became much more differentiated – but the problem-centered community remained dominated by a discourse on actual damage.

3.1 The scope gets broader and broader...

During the war, a little amount of DDT was handed over to certain sectors of the administration, the USDA for entomological studies (Leary *et al.* 1946, p. 100) and the FDA for pharmacological and toxicological studies (Whitaker 1974, p. 410). Although the first studies considered DDT as safe, there were also cases of intoxication and harmful effects after a greater exposure (Wigglesworth 1945b). Beneath the level of acute toxic effects, many scientists were concerned about potential chronic effects, like Herbert O. Calvery, scientific director at the FDA, who, as early as 1944, called DDT a "treacherous poison" (quoted from Whitaker 1974, p. 385). The question was not only about the effects on the organism but also about the different ways in which the poison entered the body. In occupational medicine, early studies had shown that the pathway of the intoxication (inhalation, absorption by the skin, or ingestion) determined the possible effects on the body. Some people argued, "The extent to which DDT will accumulate in the fat of chronically fed animals should be an important factor in the toxicological evaluation of this insecticide" (Woodard *et al.* 1945, p. 177f.). Others said: "The toxicity of DDT combined with its cumulative action and absorbability from the skin places a definitive health hazard upon its use. Symptomatically the effects on the central nervous system are the most obvious, damage to the liver is less obvious and for this reason perhaps more serious" (Smith & Stohlmann 1944, p. 992). These first studies and overviews indicated the necessity of regulation, but the results still seemed inconclusive because of their questionable transfer from animal-studies to man. Nonetheless, studies involving long-term feeding showed that at any concentration and any rate there were chronic effects. Especially at high dose levels, there were obvious symptoms like the delivery of cells, the development of cancer cells, the enlargement of certain organs (Fitzhugh & Nelson 1947).

Other disturbing effects were observed as well. Besides the phenomenon of accumulation, scientists found DDT in the milk of nursing dogs. They intensively studied the chain from the mother animal to the child (Telford & Guthrie 1945). In 1949, the USDA published that DDT-contaminated food caused, to some extent, severe health damage not to the cows, but to the calves through the milk (Radeleff *et al.* 1952, p. 277).

The scope of possible problems became increasingly wider. The PHS, who used DDT in its fight against Malaria, experimented with DDT in stagnant waters to kill the larvae of mosquitoes. Their observations were astonishing. "It killed the larvae successfully, but it also killed the fish in the pond. Moreover – and surprisingly – fish in the other pond died. Perhaps the first reaction to that event was the basis of the miracle tag DDT acquired, but, if it was, the mystery was soon dispelled. The local ducks were to blame. They were picking up enough of the DDT from the surface of the treated pond and carrying it to the other to kill the fish in the second. It was not a serious mishap, but it opened up a new line of investigation – the danger DDT carried for wild life" (Leary *et al.* 1946, p. 14). Some studies proved the toxicity of DDT to fishes (*ibid.*, p. 15) and *Daphnia Magna* (Anderson 1945). Others analyzed the negative consequences of DDT to birds, as a sensitive species for damage on nature (for a survey, see Brown 1951, p. 720ff.). These studies underlined the impression that DDT was a severe poison in nature – an idea expressed by the metaphor of ‘the balance of nature’. According to Wigglesworth (1945a, p. 113), "Chemicals which upset the balance of nature have been known before. DDT is merely the latest and one of the most violent. It can bring about within a single year a disturbance that it would take other chemicals a good many years to produce." The metaphor ‘balance of nature’ became subject to intense and controversial debates. Entomologists stated, "Actually, as far as many observers will commit themselves at the present stage of the investigation, great concern over the disturbance of the balance of nature does not seem to be justified" (Leary *et al*. 1946, p. 17). Based on this metaphor, the problem field ‘nature/environment’ came to occupy a position similar to the problem field ‘chronic toxicity’. Table 2 shows a summary of the different positions.

Fields of application, actors and interpretation	**Discourse on actual damage**	**Discourse on potential damage**	
	Problem field ‘acute toxicity’	**Problem field ‘chronic toxicity’**	**Problem field ‘nature / environment’**
Application in public health sector (insecticide)	No indication	No indication	Not in the focus
Application against epidemics (larvicide)	Not in the focus	Not in the focus	High toxicity for fishes
Application in agriculture and forestry	No indication	Not in the focus	Toxicity for birds
Application in stock-farming	No indication	Accumulation in fat and milk; transfer to calves and their menace	Not in the focus
Animal tests	Limited acute toxicity	Signs of numerous potential menaces, possibly cancer	Studies on the toxicity for fishes confirm field results
Actors	PHS/USDA	FDA (USDA)	U.S. Fish and Wildlife Service; biologists
Overall interpretation	No risk	Risk hypotheses about chronic toxicity due to accumulation	Negative influence on ‘the balance of nature’

Table 2: Discourses, empirical evidence, and risk hypotheses.

Within the debates about the negative consequences of DDT, another scientific community was noticeably involved, the biologists. However, the scientists involved did not belong to ‘mainstream’ biology; they were field biologists working on populations. As early as 1946, two biologists from the U.S. Fish and Wildlife Service stated that the intensive and extensive application of DDT caused severe harm to fishes and birds (Cottam & Higgins 1946). They observed these effects in forestry, not in agriculture. That was why the USDA initiated an eradication program against the Gypsy Moth in forests (Hotchkiss & Pough 1946). However, it was not before the mid-1950s that a broader view was taken to investigate the long-term effects of DDT on wildlife. There were different reasons for that. First, there were increasingly important research topics in this context, such as the displacement of wildlife animals from their former habitat and the human encroachment and pollution. Second, DDT was used in more fields of application than any chemical before. Third, there were particular research problems. The analysis of the effects of repeated applications of DDT required a period of at least 5 years after which the potential damage could be evaluated. In addition, there was the problem of estimating the natural fluctuation in the population of birds (Cottam & Higgins 1946, p. 44). A precise answer to the question "What is the damage?" was not as easy and it was quite impossible to demonstrate the underlying causality. Because their observations had not the design of classical experiments, field biologists were confronted with particular problems. Therefore, their influence on the scientific debate was quite marginal.

Another type of problem in the area of risk research was the difficulty of combining knowledge resources from different fields of research. As early as 1950, two zoologists explored chronic toxicological effects on white leghorn cockerels. The results were very amazing. The secondary sex characteristics were stunted and the crest underdeveloped. Since there were no further observations, their theoretical explanation came as a risk hypothesis: "The effects noted here are such that they might easily be duplicated by the administration of an estrogen. It seems, therefore, that the possibility of an estrogenic action of DDT is at least worthy of consideration. In speculating along these lines, it is interesting to note the degree of similarity between the molecular configuration of DDT and certain synthetic estrogens, especially diethylstilbestrol" (Burlington & Lindeman 1950, p. 50f.). Implicitly, they opened up a new research area, but there was no chance to develop a risk research program at that time. The field of endocrinology was not yet well established then (Colborn *et al.* 1996), so that the risk hypothesis could hardly be combined with an established normal scientific research program. Indeed, risk hypotheses have no chance of being worked out as long as there is no opportunity to design a new research program within the frame of established scientific programs.

3.2 The relative exclusivity of the problem-centered community

Before the next political event in this story, the Delany Committee, there was a new formation of the two discourses on actual and potential damage, as new actors and organizations came into the field, above all the U.S. Fish and Wildlife Service. However, the established actors, such as the PHS and the FDA and the USDA, continued to have the major influence.

In 1950, the Delany-Committee on the 'Use of Chemicals in Food Products' made the safety of DDT for the first time a topic of broad debate in the problem-centered community. This resulted in a sharp separation into two groups: proponents of the use of DDT (including the Public Health Service, the U.S. Department of Agriculture, the private and congressional farming lobby and the industry) and opponents of the use of DDT (the FDA, some university scientists, and private organizations). Proponents claimed the safety of DDT because no acute toxic effects had been demonstrated and, for this reason, they saw no need for further regulation. Opponents criticized the insufficient knowledge about chronic toxicity and called for new regulatory action. The debate finally resulted in the Miller Amendment that simplified the bureaucratic procedures and partially moved the burden of proof from the FDA to the industry. The industry was required to demonstrate that insecticides caused no health hazard by appropriate use. Before, they were only obliged to prove the efficacy of their substances and to state the correct list of ingredients. From then on, the chemical industry had to produce and to disclose toxicological data. The possibilities of a more risk-sensitive action were better than before. However, the discussion of risks was still orientated towards the model of actual damage. Therefore, the question arises why the aspect of potential damage was not able to gain any substantial impact on regulatory matters.

First, the political situation with the U.S. Department of Agriculture at its center remained relatively closed. Even though the chances of a politicization of DDT increased, the debate did not have any resonance in the public. It was a debate in the problem-centered community among its actors. The FDA became stronger in this period of the discussion but the PHS was more influential. A new actor in this context was the U.S. Fish and Wildlife Service, but the effects on wildlife were not a main issue of the problem-centered community. There was not as much evidence for the risk hypotheses as would have been needed for a revolution in pesticide politics and the demise of DDT as the general problem solver.

Second, there were also significant aspects in the evolution of agriculture that favored the use of DDT and minimized the influence of risk hypotheses. One can analyze the development of agriculture as the evolution of a large technological system. In the years after World War II, the biggest problem of agriculture was the insect problem. The first one was the problem of fertilization, known since the mid-19th century. The solution of the insect problem was a pressing need in the evolution of the technological system of agriculture owing to the installation of big monocultures. Thomas Hughes, who analyzed the evolution of big technological systems in different fields, states that these systems with their inherent necessity of expansion have to solve "reverse salients". "A salient is a protrusion in a geometric figure, a line of battle, or an expanding weather front. As technological systems expand, reverse salients develop. Reverse salients are components in the system that have fallen behind or are out of phase with the others" (Hughes 1990, p. 73). The removal of a 'reverse salient' immunizes a solution against its critics and their risk hypotheses because there are many actors interested in that solution and the costs of nonuse are considerable.

3.3 Strengthening of the risk debates against DDT

With the success of DDT in many fields of application, the programs of application grew considerably. The U.S. Department of Agriculture started some eradication programs against the gypsy moth and the fire ant. About the first one, which was implemented in 1957, the director of the involved bureau of the U.S. Department of Agriculture claimed: "We have the tools to bring this to a final solution" (quoted from Bosso 1987, p. 81). The gypsy moth was a serious problem for forestry so that there was a great enthusiasm about this program. The eradication of the gypsy moth was expected to take at least ten years. Because of the large extent of the program and its application in many landscapes, the observable damage increased. The U.S. Fish and Wildlife Service started a big observation program to analyze the damage in a more systematical way. Conservationist organizations, such as the Audubon Society, changed their fundamental perspectives from a nonpolitical to a political view of conservationism and the possibly deleterious impact of chemicals on wildlife (Bosso 1987, p. 83). The program against the fire ant was severely criticized before its beginning. As compared to the gypsy moth, the fire ant was no pest but rather a nuisance. Critics focused on that point, but they had no chance to stop the most expensive eradication program against an insect ever carried out. Serious studies showed that the natural predators of the fire ant were heavily influenced. Besides the National Audubon Society, the National Wildlife Federation joined the critics. The U.S. Fish and Wildlife Service received more funds for risk research, and the Pesticides Research Act improved general conditions for funding that kind of research.

Not only the eradication programs of the USDA established better chances for the elaboration of risk hypotheses, also other studies allowed bridging the gap between observational knowledge and theoretical interpretations. In different contexts, observations led to an increasingly differentiated perspective on the pesticide problem (*e.g.* Rudd & Genelly 1956, George 1957). Besides the economic view, other criteria such as welfare and aesthetics became more relevant. The complexity of the biological aspects was more systematically outlined and the possibilities to integrate the different views into actual research programs were improved. Two cases illustrate this thesis, the Clear Lake Case and the issue of the reproduction of birds. In the first case, small amounts of DDD[7] were added to the little Clear Lake in 1949, 1954 and 1957 to eradicate a particular kind of mosquitoes but avoid harming fishes. However, the DDD killed a considerable number of the population of certain birds. There were no signs of infectious diseases or any other known cause of death, save the large concentration of 1,600 ppm in the fat tissue of the birds, while the maximal concentration in water did not exceed 0.02 ppm. The pesticide accumulated in birds through the food chain. That result was dismaying because the idea of save and well-directed applications became an illusion. "The interesting fact to emerge at Clear Lake was that this concentration in food chains could occur, and could kill the fish-eating birds at the end of the chain. This has caused ecologists to worry in case similar effects should occur in many other ecosystems" (Mellanby 1970, p. 127).

Strictly speaking, there were two different kinds of effects, the toxicological effect on birds at the end of the food chain, on the one hand, and effects on the reproduction of the birds, on the other. DDT (and its metabolite DDE) was supposed to thin down the eggshells so that the birds could not bring up their chicken. D.A. Ratcliffe observed this effect for the first time in England in 1947/48 (Mellanby 1992, p. 70). In the mid-50s, a more systematical research program was started with comprehensive studies proving a correlation between the reproductive success of birds and the amount of pesticide they had incorporated (Hall 1987, p. 88). However, the first explanation, according to which DDT and other substances have a bearing on the calcium cycle of birds, did not appear before the early 60s. There was a remarkable time lag between the observed effect, thinning down of eggshells, and its interpretation. Obviously, risk research programs are confronted with a systematic problem because of the time lag between observable effects and the translation into programmatic risk hypotheses. Only risk hypotheses with clearly defined relations to an empirical design offer a chance for a successful risk research program (Böschen 2000, p. 349). Nonetheless, when observable effects on the natural environment increased in the 1950s and research programs included the problem field 'nature/environment', the discourse on potential damage grew stronger in the community.

However, unlike the biological effects on fishes and wildlife, the potential effect on human beings, particularly the cancer problem, became the top theme in the problem-centered community. It overwhelmed all the other aspects of the debate because of its large publicity, and it was already well established as a research program since the 1940s (Hohlfeld 1979). In 1958, the Food Additives Amendment was issued in connection with the Delany Amendment, according to which no additive may be labeled as safe if there is any hint of a potential carcinogenic effect from animal experiments. The amendment allowed the FDA to ban potentially carcinogenic substances. Consequently, the problem-centered community focused on that kind of risk.

4. Rachel Carson and the ban of DDT

The publication of Rachel Carson's *Silent Spring* in 1962 marks the beginning of an environmental movement in the U.S. It triggered a public debate on the consequences of the excessive use of chemicals in the environment. At that time, some catastrophes like the thalidomide case or the radioactive fall-out of strontium were alarming the public. However, the debate on the pesticide problem still lacked a close connection between the public and the political system. The publication of *Silent Spring* ended the era of closed debates within the problem-centered community and opened up the field to the public – Rachel Carson broke down the information barrier between these two spheres of communication (see Graham 1971, p. XIVf.).

Shortly before the book appeared, a committee of the National Academy of Sciences on Pest Control and Wildlife Relationships published a report under the same name that surveyed the available knowledge about pesticides and their effects on wildlife. It was an attempt to reconcile the scientific differences within the community – but positions were too different to allow even agreement on facts. In addition, the group of the critical scientists had grown since the days of the Delany Report. Ira Baldwin, chair of the committee, tried to gloss over the differences and to define the state of the art in the field. But the research field was so much differentiated that it was impossible to end the debate in a simple manner. The only appropriate action would have been to list the research areas of the different disciplines involved and to suggest an integrating interdisciplinary position. Yet, the final statement of the report simply said that the use of pesticides is safe and that they are a modern necessity. Thomas Dunlap concludes: "Far from being an incisive scientific statement of the problem and of projected solutions, the report merely repeated old platitudes" (Dunlap 1981, p. 116). It was impossible to end the debate in the problem-centered community because scientific perspectives on the pesticide issue were too divergent with their different focus on actual and potential damage, respectively.

4.1 The publication of *Silent Spring* and the new situation in the problem-centered community

Before Rachel Carson published her theses as a book, President Kennedy read a preprint in the *New Yorker* and asked his Scientific Advisory Board to write a report on the issues. The resulting *Kennedy Report: Use of Pesticide* started a new era of pesticides policy. It provided a brief survey of the state of the art, including the potential of biological-ecological methods and, what was more, it formulated a new direction for politics. As a general goal, the report recommended to phase out pesticides with persistent effects on the environment and human beings. It also recommended many concrete, short-term measures that involved various actors and a bundle of actions, such as a monitoring system to be installed at the US Department of Interior; the FDA should assess the exposure of insecticide-affected persons and that of the general public; the thresholds for certain substances should be decreased and the existing legal instrument for thresholds should be replaced by an authorization procedure. Finally, the report recommended that the scientific community should search for new methods of pest control and focus on basic research in the area of physiological processes. The report was also a critique of the main research strategy of the Economic Entomologists, of their continuous search for new insecticides that surpassed the previous generation of chemicals to which insects had already became resistant.

The next stage in the debate was the Ribicoff Hearings that took place from 1963 to 1966. Their main issue was the coordination of measures in the context of pesticide use. Like in other debates before, it was impossible to bridge the gap between the two different ways of analyzing the problems. Ecologists and environmental physicians could not prove their risk hypotheses by 'valid' experimentation as the experts on the other side demanded. Yet, the problem-centered community made a decisive shift, such that the difference between the two discourses turned out to be productive. The second group increasingly accepted an impact of DDT on the environment, and the first group conceded the lack of knowledge about essential phenomena (Graham 1971, p. 146). Although a dissent remained, it could now be fully developed within the problem-centered community and become also politically influential.

Under these conditions, the balance between the two discourses was adjusted anew. The ecological effects of DDT were now recognized as a serious problem, and new examples became part of the risk research program. Before the ban of DDT, the discourse on potential damage gained strength. At a summer school at MIT in 1970, scientists stated: "We recommend a drastic reduction in the use of DDT as soon as possible *and* that subsidies be furnished to developing countries to enable them to afford to use nonpersistent but more expensive pesticides as well as other pest control techniques" (SCEP 1970, p. 25; emphasis in the original).

However, the more the discourse became politically influential, the more did it focus on selected research topics, with particular emphasis on cancer. Cancer research was widely compatible with many research strategies, like in molecular biology, and cancer was one of the main issues in the political arena. This reduced the problem field 'chronic toxicity' in part to the issue of 'cancer by pesticides'. That was also an outcome of the political debate after *Silent Spring*, because the topic was already dominant in Carson's book (Marco et al. 1987, p. 195). Now the general public gained a significant impact on the definition of problems regarding environmental or health issues.

4.2 Science in the courtroom

In the mid-1960s, environmental issues of DDT became increasingly important, supported by new circumstantial evidence, such as the detection of DDT in the fat tissue of penguins in Antarctica (1965). There were two relevant changes in the problem-centered community. On the one hand, the Environmental Defense Fund (EDF) was founded in 1967 with the aim "[…] to preserve the environment through legal action backed by scientific testimony" (Mellanby 1992, p. 86). The successes of the EDF were an outcome of the powerful combination of legal and scientific competence. The EDF replaced the old strategy of the conservation funds with open confrontation in the courtroom. Based on the Delany Amendment, which allowed making potentially carcinogenic compounds a court case, the end of DDT was prepared. In 1969, a survey of the National Cancer Institute showed that DDT increased the cancer rate in mice at low level exposure. After some minor successes in some states, the EDF and its allies started an offensive against DDT at the national level. Finally, the U.S. Court of Appeals summoned the

USDA to ban DDT (Lowrance 1976, p. 168f.). At that time, in 1970, the foundation of the Environmental Protection Agency (EPA) changed the problem-centered community once more. Equipped with a broad range of influence, the EPA should bring environmental issues into the political arena, and it had to decide about the use or nonuse of pesticides. William Ruckelshaus, director of EPA, banned DDT in 1972. His decision was also a signal that the newly founded Agency was not a toothless one.

After the ban of DDT, judgements were polarized like in an ideological conflict. For one part of the public, the ban of DDT was the beginning of a new era of the relationship between humans and nature; for the other, it was an assault on the future of western civilization (*e.g.* Beatty 1973). Apart from that, the ban of DDT proved that the discourse on potential damage was politically effective.

5. The debate on DDT construed as risk constellation

Based on the narrative of the previous sections, I distinguish now different aspects of the dynamics in risk research to describe the particular path of the risk debate on DDT. Various factors can affect the evolution of a risk debate and the development of different risk knowledge resources. First, there are the cognitive factors, risk hypotheses and risk research programs. In the case of DDT, scientific expertise structured the debate, and it is an important question how different fields of knowledge involved were related to each other. Second, there are value-orientated factors. The two discourses on actual and potential damage were based on different sets of values. Third, there are institutional and contextual factors. As shown in Sect 3.2, the fact that DDT solved a 'reverse salient' in the system of industrialized agriculture was very influential on the debate on potential risks. Unlike other types, a risk research program is frequently connected to a technological research program. Through that, the character of innovation and its institutional context affects the risk perspectives. Originally, the problem-centered community about pesticide regulation was organized in quite a closed manner. After the introduction of DDT, the community increasingly opened out to include other disciplines and regulatory units. Finally, the institutional barrier between the problem-centered community and the public, as another institutional sphere, broke down by discussing *Silent Spring*.

With regard to these dynamic factors of the debate, I describe the evolution of risk knowledge by the term 'constellation of discourse change'. There was a shift in the discourse rather than a single risk hypothesis that dominated the production of risk knowledge and the regulation of DDT. In the following sections, I describe the constellation by analyzing the influence of cognitive, value-orientated, and institutional factors.

5.1 Risk hypotheses and risk research programs

Above all, the dynamics of risk research programs depends on the difference between a disciplinary and a transdisciplinary infrastructure. In classical scientific research programs, a single discipline defines the interesting issues, the main research hypotheses, the theoretical basis, and the relevant authors. Such a discipline has its own infrastructure to organize a 'marketplace of knowledge' (Lenoir 1992, p. 211). In the case of risk research programs, the situation is quite different. There are many different disciplines involved each with their particular infrastructure to define the central problems, such that the marketplace of knowledge is frequently not as closed as in the case of normal scientific programs. That makes the *scientific* definition of the central issues more difficult.

At the core of a risk research program, there is an innovative risk hypothesis, or a set of risk hypotheses, that offers a new risk perspective on a technical innovation. In the case of DDT, there was a set of risk hypotheses, based on the discourse on potential damage, that originated from the first generation of pesticides in chemical insect control system (Sect. 2). There was also an empirical design to study the different risk hypotheses about DDT. Moreover, the debate on the influence of DDT on the balance of nature established a new problem field. Because of the wide range of applications of DDT, new opportunities appeared to study the risk aspects of this innovation. In the course of time, different biological aspects were discussed and the eradication programs of the USDA enabled a systematic risk assessment of the biological effects of DDT. Thus, the consequent expansion of the application of DDT in different fields catalyzed the evolution of risk research programs, particularly on the effects of DDT on the balance of nature, by providing possibilities for empirical tests.

The main problems of establishing a risk research program are problems of connection to established research programs and to an empirical design. The first problem is illustrated by the tendency to reduce risk research to the cancer research program. With respect to the increasing dominance of the molecular paradigm in cancer research, the cancer inducing potential of DDT was a very interesting research area. Moreover, there was a strong public interest in this kind of research. The openness towards the political system and the public has repercussions on science itself in that scientific work is aligned with a new political framework. In this way, the cancer risk of DDT became a main issue, although the influences on nature were much more serious. The second problem, connection to an empirical design, became obvious in the context of the endocrinological effects of DDT. First published as a risk hypothesis in 1950, it was impossible to provide an empirical test design let alone a theoretical explanation. Because endocrinology was established only in the 1970s as a separate research area, it was impossible to work out the risk hypotheses already in the 1950s, and it was overlooked until the 1990s when the debate about the effects of endocrine disrupters was put on the agenda of public discourse. However, these problems of connection are not only cognitive ones, they also have an institutional basis. A risk hypothesis and its main research programs are often formulated in different institutions resulting in two gaps, a cognitive and an institutional one.

5.2 Epistemic and political values: the influence of different discourses

The ‘marketplace of risk knowledge’ can be open in two directions. First, it is open towards the political sphere. Problem-centered communities are a mixture of scientific and administrative expertise. That results in a continuous tension between facts and political interests. Risk knowledge is always a kind of political knowledge, because the definition of risk situations determines a course of action to protect the public or a part of it against the agreed hazard. Secondly, there is a possible connection to the general public. Carson’s publication of *Silent Spring* broke the communication barrier between the problem-centered community and the general public.

Before the introduction of DDT in agriculture, the two discourses on actual damage and on potential damage preformed the later risk debate. However, there was a gap and a competition between these two discourses. Both were orientated towards different sets of epistemic and political values. The discourse on actual damage was based on the framework of occupational medicine and mainly concerned with the protection of farmers. The discourse on potential damage referred to animal experiments on the physiological effects of pesticides. Their research aimed at describing chronic intoxication – a potential public health hazard – and was mainly concerned with the protection of consumers. The continuous polarization of both discourses essentially determined the dynamics of the risk debate.

Although each of the discourses provided a plausible problem field, the first one offered better guidance for action, such that early political regulations focussed on actual damages. It was better related to established epistemic values and offered facts that could be reproduced in experimental designs. In contrast to that, the discourse on potential damage was much more influenced by political values and tried to revise the methods of risk assessment. It offered a new perspective of risk research by drawing more on circumstantial evidence than on a testable hazard. Therefore, its theoretical and empirical design was rather inconclusive at first. However, once the problem field ‘balance of nature’ was established, new approaches to empirical evidence opened up. Moreover, the new problem field transported a new value frame into the debate, the protection of the natural environment. In the overall problem-centered community, however, it still remained a matter of debate what should count as damage.

The situation tremendously changed when the pesticide problem entered the public sphere. After the publication of *Silent Spring*, also the public gained impact on the dynamics of the risk debate. Between the public and a problem-centered community there are often considerable differences regarding values, framing strategies, perspectives on problems, and preferred solutions (Neidhardt 1994). Because of a shift of the problem-centered community towards consonance with the public, the general focus of risk research was adjusted anew. As a result, potential damage became the guiding principle for risk research in the case of DDT. The insights from that perspective acquired the status of robust facts and became the reference point for regulation processes. But not only there. Different sociological analyses have shown that, by the end of the 1960s, a new era of social reflectivity regarding environmental concerns began. Well-known effects with a wide impact in space and time have been analyzed since (Gill 1999). The 'global environment' has become the new field of risk expectation (Böschen 2000, pp. 324ff.).

5.3 Institutional settings

Institutional structures, including the openness or closeness for others to participate in relevant debates, shape the perspective for defining issues in risk research. In the 1940s and 1950s, the debate on the risks of DDT took place in a relatively closed problem-centered community. Their main actors were known and their approach to defining risks showed a stable constellation. The dominant risk definition referred to the dominant discourse on actual damage. During the 1950s the set of actors increased, first by the U.S. Fish and Wildlife Service and second by researchers from academic institutions. However, the problem-centered community still remained relatively closed. This changed only in the 1960s, when the public became involved in the debate and the problem-centered community lost its autonomy in defining the issues. During that change, also new actors entered the stage. The EDF with its combination of scientific and legal competence developed a completely new strategy. In this way, the problem-centered community was opened dramatically and the discourse on potential damage became the new standard.

Conclusion

The analysis of the case study on DDT illustrates the general complexity of risk knowledge production. In this case, a shift of dominance among the two discourses involved led to the important result that insights of the discourse on potential damage acquired the status of robust facts. I suggest that analyzing the 'constellation of discourse change' in terms of cognitive, value-orientated, and institutional factors may help understand the development and acceptance of risk knowledge. Such studies might not only be useful for understanding risk research itself but also for the goal of precaution. If we want to learn something about the possibilities and problems of a timely production of risk knowledge, we first have to study the dynamics of risk research. With reference to different risk constellations, possibilities and restrictions of risk knowledge production can then be evaluated.

Notes

[1] DDT has been subject to two kinds of nonchemical studies. On the one hand, Dunlap (1981), Bosso (1987), and Russell (2000) analyze the politics of DDT by looking at the complex political process of regulation. However, they are not interested in the process of knowledge production. On the other hand, there are some studies on the history of DDT with very broad scopes and many details (see Simon 1999).

[2] The WBGU (1999) for example has argued along these lines by starting with the classical risk definition (product of probability and damage) and then distinguishing types of risks that are open to contextual factors. Among these factors are the problem of uncertain knowledge and the probability to

become a public issue.

[3] These chemistry-related aspects of the industrialization of agriculture are but one part of a whole set of interrelated developments including mechanization, monocultures, and innovations in transport and warehousing.

[4] The PFDA regulated food production and distribution and prohibited the selling of poisonous or spoilt food. The FIA demanded that producers of insecticides declare the various substances in their formula and undertake the efficacy of their products.

[5] Instead of referring to the various meanings of the term 'discourse', I use it in the sense of a cognitive framework of relevant social actors as represented by communications during a certain period. The social actors may be a group or community of scientists, but also members of the general society.

[6] The British based their threshold on another expertise.

[7] This is the dichlor analogue of DDT.

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Stefan Böschen:
Institute of Sociology, University of Augsburg, D-86159 Augsburg, Germany;
stefan.boeschen@phil.uni-augsburg.de