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The Dialectics of Arms Control Norms and Technological Progress: Theoretical Reflections and Empirical Illustrations

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(-First draft – thank you for not quoting without our permission-)

ABSTRACT This paper discusses the interplay between arms control and technological progress. According to the dominant conception of this relationship, technological progress translates into armament dynamics, which in turn is sometimes regulated by arms control agreements – thus, arms control is understood as a reactive measure. Pointing to a so far neglected effect of arms control, we reverse the mainstream assumption and suggest that arms control is not only trying to halt technological development, but also may trigger it. Two examples of multilateral arms control – the Comprehensive Test Ban Treaty and the Anti-Personnel Landmines Convention – are used to empirically illustrate the argument. In our concluding remarks, we discuss the implications of the findings for the practice of arms control.

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1. Introduction: Research Interest and Aim of the Paper[1]

How states develop, organize and regulate their instruments of force is a key aspect of international security. Arms control, disarmament and non-proliferation efforts, as well as several aspects of international humanitarian law aim at restricting the military capacities of states, eliminating certain categories of weapons, the relinquishment of the use of certain weapons and preventing dangerous arms races. However, a cursory glance at the history of arms control, especially in the last century, reveals an interesting trend: not only have the international control mechanisms and legal instruments for arms development, accumulation and use tightened considerably, but weapon-technological developments have also progressed enormously – increasing the levels of destructiveness (precision and lethality of any single weapon) on the one hand and creating the illusion of "smart" combat technologies on the other.

Motivated by these parallel developments, the paper aims at taking a closer look at the dynamics between arms control and technological progress pursuing the question of how the two influence each other. In a first step, the paper reviews the literature on this matter, thereby discussing the impact of technological progress on armaments and war, factors stimulating technological progress and reasons why it is difficult to control it. After having shown that existing scholarship tends to consider the relationship between technology and arms control to be one-directional – namely arms control efforts as reactions to technological innovations, the paper suggests considering the other direction as well. According to the argument, the relationship is rather a dialectical one: Not only does arms control react to technological progress, but arms control measures itself may serve as a factor (among others) which stimulates technological innovation and, in some instances, armament dynamics. This claim is illustrated by two case studies where the adoption of a multilateral disarmament treaty triggered technological development even within non-parties: After the adoption of the Comprehensive Test Ban Treaty (CTBT), a major and costly transformation of the nuclear weapons research in the U.S. occurred, including the launch of new research programs and the acquisition of new research facilities. After the adoption of the Anti-Personnel Landmines Treaty, several research programs seeking to find substitutes for anti-personnel landmines have been launched, as a result of which some sophisticated weapon systems are being produced.

The paper concludes with a discussion of the implications of our findings: What are possible ways to deal with the paradox that in the end, arms control may trigger new armament dynamics and thus produces effects it is supposed to restrict? What are possible ways to deal with the problem that arms control measures might disadvantage less technologically advanced countries, which are not able to circumvent its provisions with sophisticated technologies? Should these problems lead us to question the very raison d'être of arms control?

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2. Theoretical Reflections: Technology, Armaments and Arms Control

While it is obvious that technology, armament dynamics and arms control are closely linked, the conceptions about the nature of these relationships – including causality, directionality and sequence – differ considerably. Generally, the majority of existing scholarship tends to treat arms control efforts as reactions to armament dynamics which are advanced by technological innovations. However, it is disputed whether technological progress is an autonomous force dictating political and military options, as suggested by the idea of the "technological imperative", or whether technological progress itself is a function of political, military and economic considerations. Even if technological progress is considered the independent variable, one can still think of different forms of causality it might exert on armaments dynamics, e.g. functioning as a cause in the narrow sense, as a trigger or as an enabling condition. If, on the other hand, technological progress is conceived of as depending on other factors, the question remains which of them are crucial. After having discussed existing approaches and shedding light on these problems in the first part of the following section, in the second part, we point to an aspect that has been (almost) neglected so far: Not only do technological developments serve as a reason for arms control efforts, but arms control itself may serve as a factor stimulating technological innovation and, in some instances, armament dynamics.

2.1 How Technological Progress Affects Arms Control

Following the general view of international arms control processes as reactions to new technological realities and armament dynamics (Müller/Schörnig 2006: 30-32), first it is necessary to give a brief overview of the role technological progress has historically played for armament dynamics and the conduct of warfare. Subsequently, it is shown how the nuclear revolution has added significance to arms control, turning it into a basic instrument which is supposed to prevent the destruction of the mankind. The last two parts show the ambiguous nature of technological progress as being hard to control on the one hand and offering some important opportunities to conclude and implement arms control agreements on the other.

A brief history of technological progress, war and arms control

The history of war cannot be written without considering the role of technological innovations. They have been a major factor (though not the only one) influencing the nature of warfare including its organization, strategy, tactics and, in particular, its destructiveness – war is, as Martin van Creveld (1991: 1) puts it "completely permeated by technology and governed by it". Three effects of weapons innovations in particular had a major impact on war: Increasing precision, increasing lethality and increasing the distances of impact (Müller 1992: 35-42). They were accompanied by increased difficulties to gain protection against them (Müller/Schörnig 2006: 25).[2] After the

[2] One of famous examples for these effects is the innovation of the crossbow in the 11th century that allowed effective fighting at greater distances because of its penetration power. Due to its capabilities to be targeted precisely and to snap through the armour of the knights and the little level of skills required for its use, the crossbow also put at risk social relations of that time by threatening the unique position of the knights – this is seen as the main

reinvention of the crossbow and the beginning of the use of gunpowder in the Middle Ages, major technological breakthroughs came with the industrial revolution bringing about a tremendous increase in the numbers of war victims caused by magazine-loading firearms, machine guns, explosive bullets, mines and torpedoes as well as larger devices such as tanks, battle jets, steel-hardened battleships and submarines (Smith 2009: 112). These developments required a restructuring of the armies meaning a higher demand for centralization, co-ordination and clear commando hierarchies necessary to use the new battlefield technologies and to resist them (Müller/Schörnig 2006: 26-27).

The pursuit of technological progress gained new momentum and quality as an essential feature of the superpower confrontation during the Cold War. Technology turned into “a major area of strategic competition in its own right” (Gelber 1974: 522) in which each of the two parties tried to achieve superiority. After the destructive potential of the weapons has been growing for decades, new trends in military technology summarized under the catchword the Revolution of Military Affairs (RMA) promise precise and discriminating warfare and thus create the illusion of "smart" technologies.

Especially in the second half of the twentieth century, the progress in weapons-technological developments has been paralleled by the tightening and deepening of the international control mechanisms and legal instruments for arms development, accumulation and use. This is not to say that arms control is the product of the age of modern – especially nuclear – technologies. Rather, the emergence of all the military innovations described above has been continuously “hunted” by efforts to constrain or at least regulate their use: First arms control agreements date back to the Ancient world, when the Philistines tried to hinder the acquirement of iron-based weapons by the Israelites; they have been succeeded by the prohibition of the crossbow in the Middle Ages (see fn. 2, p. 2) and by several agreements concluded in the 19th and 20th century and belonging to the so-called Law of the Hague (such as the St. Petersburg Declaration prohibiting exploding bullets deemed to cause unnecessary suffering, the Hague Conventions prohibiting the use of poisonous weapons and so-called Dum Dum bullets and the Geneva Protocol prohibiting poisonous gases and bacteriological warfare (Shaw 2003: 1056, Greenwood 2008: 22-28). Despite this long history, it is the nuclear revolution that has attributed unprecedented relevance to arms control (Krell/Minkwitz/Schörnig 2004: 556): Its ability to stabilize the system of deterrence by maintaining nuclear balance and thus to prevent the nuclear destruction of mankind justifies the assessment that arms control “owes its existence to the unimaginable dangerousness of instruments of modern warfare (…) and is the child of modern weapons technology” (Müller 1989: 194, translation ER).

Thus, while technological progress has always shaped war and stimulated arms control efforts, it is against the background of the arms race between the superpowers during the Cold War that most of the ideas on the impact of technological innovation on armament dynamics evolved. We present some of those dominant conceptions in the following section: the idea of the technological imperative and its criticism, explanations based on *internal* political, military and economic configurations, explanations based on

reason for the efforts of the Second Lateran Council in 1139 to prohibit the weapon (Croft 1996: 24, Müller/Schörnig 2006: 31-32).

external stimuli pointing to action reaction chains between the opponents and *holistic* explanations trying to integrate all of the relevant factors.

The idea of the technological imperative and its critique

The idea that armament dynamics are driven by the so-called “technological imperative” – meaning that “a major driving force behind this race lies in the self-sustained, science-based momentum of modern military technology” (Thee 1989: 41) – has been advocated by prominent arms control theorists such as Jerome Wiesner, Morton Halperin and Herbert York. We can distinguish a unilateral and an interactive version of technological progress. According to the former, weapon-technological progress follows its own logic resembling that of a perpetuum mobile: Its continuing impetus is given by scientists and weapon designers whose human curiosity motivates research, which, in turn, not only produces knowledge but also the desire for more knowledge leading to more research and so on (Brauch 1986: 433-436). Beyond curiosity, another basic component is the quest for perfection forcing each side to continuously modernize its (weapon) technological achievements (IPRA 1976: 26). Subjected to the “lure of technology” (Evangelista 1988: 222), weapons scientists are responsible for major technological breakthroughs. The latter function is that of an impulse for the development of new military capabilities – once new technological options are available, scientists come up with their possible military applications; in other words, military-technological progress does not respond to requirements but to possibilities (Albrecht 1986: 458-459). Once developed, new military options in turn shape the military doctrine and strategy (Thee 1986: 42-48, Evangelista 1988: 12): “First came the weapons; then they had to be fitted into a presumed tactical doctrine which in turn had to be fitted into an illusory strategy, usually elaborated by armchair warriors” (Thee 1986: 45, quoting Lord Zuckerman, the former scientific adviser to the British Ministry of Defense). Adhering to this conception of a technological imperative, Dieter Senghaas diagnosed autism as an essential feature of the East West Conflict (Senghaas 1971), suggesting that both sides pursue self-referential policies while ignoring the behavior of the other side.

On the contrary, the bilateral version of the technological imperative, as it has been elaborated by Barry Buzan (1987), points to the interaction between the actors as a further component of the technological imperative. In Buzan’s view, two major features characterize the international system: the technological permeation of modern industrialized societies and the security dilemma resulting from international anarchy. Since technological development is an important factor determining the international status of modern industrialized societies, states find themselves in a steady technological competition with each other. Uncertainty about future technological developments, combined with the realist assumption of the security dilemma, means that the (military) technological advancements of the enemies are considered as a threat to the state’s security. This induces a dynamic of technological catch-up and even of anticipation – the parties attempt to acquire a certain technological status before their opponent can do so and perceive the need to assess the military potential of all technological innovations.[3]

In both of its versions, the idea of the technological imperative has encountered criticism that disputed the vision of technology as an independent force and highlighted the importance of human agency. Donald MacKenzie (1987: 195-196) considers it as insufficient to treat technological development "in isolation from organizational, political, and economic matters" and emphasizes the importance of social factors instead of "simplistic technological determinism", since the latter cannot explain why different technological paths are taken in similar technological areas. The importance of social institutions and actors is also stressed by Judith Reppy (1992: 75), who argues that "the identification of technical problems and their solutions is negotiated between actors, not pre-ordinated by a physically determined trajectory of independent process of its own". The political dimension of this critique is revealed by other authors: Harald Müller points out that the claim of a quasi physical necessity inherent to the argument of the technological imperative is serving as an instrument for decision-makers to legitimize the escalation of conflicts and to undermine arms control agreements. References to such ungovernable forces unnecessarily narrow political room for maneuver in an area essential for the further survival of mankind (Müller 1989: 173, 188, Müller/Becker 2008: 103). These arguments aim at de-naturalizing technological advancements, because only if the technologically stimulated arms race is regarded as man-made, there is a chance for it to be undone by using political instruments.

Alternative explanations: complex interplay of technology, politics and military

In line with the critique of the technological imperative, other approaches conceptualize technological progress as being determined by political, military, economic and individual factors: The political explanation stresses the threat perception of political decision-makers as the basis for the formulation both of technological and military strategic requirements; accordingly, the military explanation attributes the same function to military services that influence both politics and science in order to increase research and development budgets and efforts (Brauch 1986: 433, Brauch 1989: 5). The economic explanation, as it has been brought forward by the proponents of the existence of a military-industrial complex, focuses on the interests of the arms industry which has the power to influence political and military decisions (Brauch 1989: 18). Individual explanations try to unmask the technological imperative as resulting from individual motivations such as the fascinations with one's own object of research, the interest to preserve one's field of activity (Müller 1989: 186-187) and the psychological desire for prestige (Gelber 1974: 528).

While – sometimes implicitly – preferring the interests and the position of one group as a starting point, most of the observers however acknowledge the complexity of the relationships between science, the military, economics and politics:

> "Obviously, such complex phenomena as arms races cannot be explained in a reductionist way, restricting motivation, causation and dynamics to one class of agents

3 Müller 1989: 175-187, Reppy 1992: 75, Voronkov/Grin/Smit 1992: 4, Müller/Schörnig 2006: 64.

> only. Different stimulants will tend to combine, interact and overlap, even if at times one particular motive force may predominate" (Thee 1986: 101).

This complexity renders it impossible to develop a general model with clearly directed causalities and applicable to all of the cases; instead, integrative explanations depicting a co-determination of all these factors and/or acknowledging possible variance between the cases have been developed. Pursuing the question whether weapons innovations are motivated by supply or demand factors, Mary Kaldor (1986: 595) suggests a mutual influence and identifies war as "the mechanism for reconciling demand with supply". Marek Thee assumes a combination of the forces such as vested socio-political interests, the technological drive and "the military's natural inclination to strive for "a better and bigger bang" (Thee 1986: 50) that leads to a "powerful self-sustaining armaments momentum" (Thee 1986: 102), which is further accelerated by the international environment. The availability of respective technology is identified by Kosta Tsipis as a necessary, but not a sufficient condition to participate in that armaments momentum – while the proponents of a technological imperative only consider doctrinal and strategic adaptations to technological options, Tsipis states that the latter may as well adapt to the former: "So it happens that sometimes technology drives policy, and at other times policy needs to guide the development of technology" (Tsipis 1989: 1-2). Also considering technology as one element among others, Matthew Evangelista takes a closer look at how technological possibilities and weapon ideas translate into concrete programs within the political systems and identifies several stages of this process, at which different actors of the political and military system are involved (Evangelista 1988: 56). The multiple implications of such technological decisions are presented by Donald MacKenzie, who argues that while technological possibilities form the framework for such decisions, the pursuit or non-pursuit of certain options has direct consequences for "particular corporations, project offices, even whole branches of the armed services (…) as a multiplicity of individuals' careers" (MacKenzie 1987: 202).

So far, this part has shown that while technological progress does indeed play a crucial role for arms dynamics, it does not produce them automatically – rather, technological and military innovations proceed in a social context that both adapts to them and shapes them.

Why technological advancement is difficult to control

Shaping technological progress means more than formulating specific requirements and providing funding for special projects – during the Cold War, it also meant arms control efforts, which were, however, deemed to chase after technological innovations as continuously as they were unsuccessful (Liebert/Neuneck 1992: 51): While the developments in military technology are oriented towards the future and supposed to affect the strategies and politics of tomorrow, arms control was trying to cope with yesterday's weapons technologies (Brauch 1989b: 5-6). Although the arms dynamic was "not so much one of quantities as of qualitative expansion" (Thee 1986: 1), arms control efforts prioritized counting the numbers of arms (and even there, agreements have been achieved on higher instead of lower levels), leaving military research and development unrestricted. Why has it been so difficult to control innovation and weapons modernization?

One reason discussed is the difficulty, or even impossibility, to restrain ideas – even if one party abandons the further pursuit of an idea, there is no certainty that this idea will remain uncovered by others (Gelber 1974: 530). Furthermore, since it is often difficult to anticipate the effects and the utility of technological discoveries, a dilemma of control emerges:

> "when a technology is still in the early stage of development, it is difficult to assess all its implications; when it has come at a state that is possible to grasp its implications, both positive and negative ones, the technology has in many cases got too much momentum to be stopped or even to be re-oriented." (Grin/Smit/Voronkov 1992: 69)

In other words, at a stage when technological progress *could* be controlled, it is not clear whether it *should* be, and when it becomes clear that it *should* be, it *cannot* be controlled any longer. To halt technological progress means attempting to regulate objects not existing at the moment of the control effort, this is why arms control has for a long time been considered as a reactive instrument, oriented towards past developments and established technologies (Bertram 1978: 14; Liebert/Neuneck 1992: 52). Criticizing this notion and trying to overcome it, the concept of preventive arms control was suggested at the beginning of the nineties. Starting from the notion of technological progress as a stimulus for arms dynamics (Müller/Neuneck 1991/1992), the concept aims at limiting weapons innovation processes and blocking certain military options at their very beginning (Petermann et al. 1997: 47, Brauch et al. 1997: 63). For this purpose, it is not sufficient to restrict research and development of endeavors with a clearly military footprint; additionally, so-called constructive technology assessments that would include the possible military, social and ecological consequences of technological innovation need to be carried out (Grin/Smit/Voronkov 1992: 69, Neuneck/Liebert 1992: 66). This also directly addresses the dual-use potential of most technologies: The challenge would be to identify the points where the paths of military and civil development split and to restrict the former while maintaining possible benefits of the latter (Brauch et al. 1997: 54-56).

However, exercising preventive arms control would require monitoring and verification of ongoing technological developments. Whereas prospects for reliable verification increase the chances for arms control agreements, verification of technological developments is difficult due to two characteristics: their incremental nature and secrecy. Since most of the technological innovations are rather incremental than revolutionary, meaning gradual improvements or new combinations of already existent elements, it is difficult to define the point at which progress begins – "which weapons are 'identical' and hence allowed, which are 'new' and hence forbidden?" (Bertram 1978: 12-13, Müller 1989: 178). The issue is further complicated by the high degree of secrecy and intransparency characterizing the research and development phase – this also lowers the chances for adequate verification of a possible agreement and therefore reduces the willingness of the negotiating parties to conclude it (Müller 1989: 190, Bertram 1978: 6).

Another reason for the asynchronous relationship between technological developments and arms control efforts is the pace and dynamics of technological progress. The shadow of the future accelerates the development of weapon technologies in a twofold way: First, research and development efforts are stimulated by worst-case scenarios of future technologies that might be developed by the opponent (Thee 1986: 112). Second, after every technological breakthrough there is the risk of imitation which is tried to be mitigated in advance by further modernization so as to remain in a technologically leading position (Müller/Schörnig 2006: 105). In turn, the weapons are considered obsolete at the very moment they come into being, or, as Harry G. Gelber (1974: 529) puts it: "since most technical advantages are relatively short-lived, the achievement of one merely creates fresh impulses to search for its successor."

When comparing processes of arms control and of technological development, the latter seems to have a structural advantage lying in its inertia and path dependence, whereas arms control is vulnerable to diverse shocks: While the life-cycle of a product is short, the time needed for its development is long and the process itself hard to reverse because of high investment costs, the follow-on imperative, interoperability and synergies between different technological elements. Hence, research and development projects usually proceed "undisturbed by the outer political environment, be it the state of arms control negotiations or change of administrations" (Thee 1986: 45). Arms control efforts, on the other hand, need more time, since they are based on the interaction between at least two parties and therefore, are contingent on their will to cooperate (Müller 1989: 190). Moreover, they seem more vulnerable to external factors like a general deterioration of the political climate, the change in political leadership or technological improvements introducing an imparity between the partners. Both the real occurrence of technological progress and its very foreseeability might endanger the feasibility and the stability of arms control agreements, since the latter become the less attractive the better the prospects to technologically bypass the discussed and/or agreed restrictions (Bertram 1978: 1-6).

Technological chances for arms control

Whereas there are serious difficulties for arms control to regulate technological advancement, it needs to be considered that some of the attributes complicating arms control may also serve to enable it. In other words, technology poses not only perils, but also chances for arms control by potentially increasing the will of the states to bind themselves via several ways. First, while the chance to render an agreement obsolete by technologically circumventing its provisions lowers the incentive for the opposing party to agree to it, at the same time it is deemed an advantage when considering the attitude of the domestic public: If the latter is skeptical towards arms control because it is perceived as endangering national security, the perspective of technological compensation for such (perceived or real) security losses makes it easier to domestically justify the conclusion of arms control treaties (Senghaas 1972: 96, Krell 1977: 193). Second, it can be argued that modernized and new weapons strengthen one's own bargaining position because they can be used as so-called bargaining chips – in return for the willingness to control them, higher limitations may be demanded from the opponent (IPRA 1976: 40).[4] Third, while the verification of agreements aiming to restrict research and development is considered to be difficult, new technologies might prove helpful in monitoring existing arms control agreements: Modern intelligence, communication and data collection techniques make it easier to reliably monitor

[4] However, the bargaining chip idea has been criticized with the argument that the weapons pretended to be acquired only as bargaining chips have not been disarmed but instead did stimulate further armaments and become part of the military arsenal (IPRA 1976: 39-40).

compliance with arms control agreements – the reduced chance of being cheated on or the increased chance to disclose cheating might thus increase the willingness of the states to bind themselves (Müller 1989: 196).

2.2 How Arms Control Might Affect Technological Progress

So far, the paper has shown how technological progress, embedded in a national and international political context, might contribute to armament dynamics and how it might have a negative or positive impact on efforts of arms control. The following section will discuss the other direction of the relationship between technology and arms control: Assuming arms control is the independent variable, the question of how arms control might restrict technological progress or allow for it is pursued. While, so far, we have presented the state of the art, in the remainder of the paper we aim at illuminating one argument which has not received much attention – namely, that arms control may also provoke technological developments and armament dynamics. Accordingly, we suggest a modification of the one-way conception of arms control as reacting to technology – rather, the adequate image would be a spiral where arms control and technology constantly react to each other.

This argument starts from the basic assumption that it is impossible for arms control agreements to avoid a certain level of permissiveness: Defining what kinds of weapons need to be reduced or are forbidden in future means that at the same time, other categories remain allowed or seem more acceptable (Tannenwald 1999: 442). This effect is a pre-condition for three possibilities to compensate for qualitative restrictions: upgrading non-restricted categories, shifting to non-restricted categories or developing technological alternatives.

While at least a few authors (Gelber 1974: 524, Senghaas 1972, Bertram 1978: 12-15) have pondered such effects, none of them has inquired into them systematically and provided empirical evidence of how such processes take place. Aiming to fill this deficit in the following, the paper picks up this claim and tries to illustrate it with two case studies – the Comprehensive Test Ban Treaty and the Anti-Personnel Landmines Treaty. It is shown that both multilateral treaties, while having achieved high degrees of compliance even by non-members, have also stimulated circumventing strategies identified above, namely shifts to non-restricted testing methods and weapons and endeavors to procure technological alternatives.

3. Empirical Illustrations

3.1 Nuclear Arms Control: Impact of the CTBT on Technological Progress

The long road towards a comprehensive test ban treaty

Ever since the beginning of the atomic age, nuclear testing has continuously accompanied the rise and the establishment of new nuclear powers. Explosive nuclear tests were carried out for a variety of technical and political reasons (Fitzpatrick/Oelrich 2007, Goldblat/Cox 1988).

The political motives typically followed either security or status considerations (or sometimes both). A state would carry out a nuclear test to show resolve and to flex its muscles during periods of tension. Or it could opt to simply demonstrate its power and technological prowess in times of peace. These nuclear tests were thought to bolster the status and prestige of a state both in the international arena as well as domestically.

Still, the main rationales for nuclear tests were a number of technical aspects pertaining to the complex physics of nuclear weapons (for an overview see Garwin/Simonenko 1996). Nuclear tests were used to validate ("to certify") nuclear weapons and make sure that the actual warhead performance corresponds to its nominal design. This certification process was generally carried out for both new and for ageing nuclear weapons. There are only a few exceptions to this rule: the Hiroshima-bomb, a simple and basically fail-safe uranium weapon was never tested (as a consequence, the South African nuclear arsenal – consisting of a few weapons of this type – was never submitted to a test); some new warheads were not tested, because they were modifications of older weapon designs, which already had a rich test pedigree; and Israel's secret arsenal was probably never tested either. For all other weapon types – plutonium based weapons, more sophisticated uranium warheads, or substantial modifications of existing designs – some degree of testing is practically indispensible, if a state wants to be confident on the performance and safety of its nuclear arsenal. Hence, at first glance one could conclude that a global ban on nuclear testing would curb most weapon improvements for an established nuclear power, and would close most weapon options to a nuclear newcomer. A ban therefore would serve the double purpose of severely constraining the qualitative nuclear arms race and of hampering the emergence of new nuclear powers.

It was exactly this disarmament and non-proliferation dimension that has made a global nuclear test ban an attractive option for arms control advocates for the last decades. Indian Prime Minister Jawaharlal Nehru called for such a treaty already back in 1954, and numerous similar appeals were voiced in international fora in the subsequent decades (for a historical account of the test ban campaigns, see Goldblat/Cox 1988, Fetter 1988, Hansen 2006 and CTBTO 2010). Still, it took forty years after Nehru's appeal until official negotiations on a Comprehensive Test Ban Treaty (CTBT) started. CTBT negotiations started in 1994 and were concluded successfully in 1996 (for a detailed account see Ramaker et al. 2003, Hansen 2006).

But already during the negotiations of the treaty a number of controversial issues came to the fore: What was the overall objective of the treaty? What should be prohibited and which activities should be allowed under a nuclear test ban treaty? And to what extent should the treaty prevent nuclear weapon modernization and new development efforts? (Arnett 1994, Arnett 1996)

The political struggle over the scope of the CTBT

It was not surprising that the official nuclear weapon states (NWS) campaigned for a rather lax scope of the treaty, which – short of large explosive nuclear tests – would give free rein to their nuclear weapon laboratories to continue their mission, i.e. to maintain, modernize and optimize their arsenal with a range of technical activities, which should also include "low-yield" testing. It was equally not surprising that this foray was met with distrust and rejection by many non-nuclear weapon states, especially within the non-aligned movement (NAM). NAM countries called for a much stricter and more comprehensive scope, which should not only ban any sort of explosive nuclear test – including low-yield explosions – but should also address the vast range of technologies which could be used to modernize and optimize nuclear weapons. It was in this context that the Indonesian delegation called to also ban "virtual testing", i.e. specific experiments and numerical simulations on supercomputers, which emulate an exploding nuclear weapon and which could be used as a surrogate for explosive testing (Schaper 2007: 222).

The conference outcome was a compromise between these extreme positions: NWS had to concede that a *comprehensive* test ban treaty would ban *any* nuclear test, i.e. any explosive test of a weapon involving a nuclear chain reaction: thus, neither low-yield tests nor "peaceful nuclear explosions" would be allowed under a CTBT. On the other hand, disarmament advocates had to accept that the NWS would not renounce maintaining their existing arsenals and would therefore not accept further technological restrictions on the test ban. Thus, non-explosive tests (for example on the computer), but also explosive tests without release of nuclear energy (so-called subcritical tests) would be allowed under a CTBT. Further, any other simulation experiment, which mimics parts of the physics of a nuclear weapon, would not be restricted by the treaty, as long as it did not produce a nuclear chain reaction.

The restriction of the CTBT´s scope to explosive tests also had a pragmatic reason: these tests – whether carried out underground, under water or above ground – always leave strong physical signatures (seismic and acoustic waves as well emission of radioactive noble gases), which can be registered by a network of appropriate monitoring stations across the globe. On the other hand, virtual tests on supercomputers and small-scale experiments mimicking aspects of nuclear weapon physics cannot be monitored in the same manner. Hence, only explosive nuclear tests seemed to be effectively verifiable and were therefore the least common denominator between status quo-oriented NWS and disarmament-prone NNWS.

The struggle over the scope of a CTBT left its marks in different parts of the treaty text (see CTBTO 2010). Whereas the preamble emphasizes the importance of nuclear disarmament, in the articles of the CTBT we merely find the ban on nuclear tests, but no prohibition of nuclear weapon modernization and maintenance, let alone any reference to nuclear disarmament. This juxtaposition of preamble and the articles of the treaty shows the inherent tension within the CTBT. The spirit of the treaty, codified in the preamble, sees the CTBT as a fundamental contribution to the larger goal of nuclear (and even general and complete) disarmament. The wording of the treaty, enshrined in the norms (i.e. the articles) of the CTBT, is merely the renouncement of a specific technological practice of the nuclear weapon laboratories: explosive testing.

Compliance and adaptation to the treaty: the U.S. example

The CTBT was signed by all five official nuclear weapon states; even though it has not been ratified by the U.S. and China yet, all NWS comply with the test moratorium (i.e. the letter of the treaty). Still, ongoing modernization efforts and large science programs within some NWS cast some doubt on the contribution of this treaty to the goal of nuclear disarmament (i.e. the spirit of the treaty). A short description of the American post-CTBT landscape might illustrate these findings:

President Clinton's signature to the CTBT in 1996 marks the beginning of a substantial transformation of the U.S. nuclear weapons complex. The new overall strategy is mainly conservative and focuses on the maintenance of the existing nuclear arsenal, the preservation of skills and knowledge within the nuclear weapons complex and the continuation of the test moratorium (which already began in 1992, although only informally). For this purpose, the Department of Energy (DoE) designed a new work program for the weapon laboratories, the *Science Based Stockpile Stewardship Program*.

The program is supposed to achieve a threefold goal: to enhance the skills of the maintenance personnel to detect ageing defects in a timely manner. To broaden the theoretical understanding of nuclear weapons and improve the ability to simulate them (both in numerical models as well as in experimental settings). Finally, the program is supposed to contain high-end science elements to attract the best junior scientific staff to the nuclear weapons laboratories.

This program, whose official narrative is to keep the U.S. deterrent safe and reliable, appears to be extremely costly (Schwartz 2009). It is indeed somewhat bizarre, that the costs of the nuclear weapon complex of the first decade after the CTBT topped all previous decades where the U.S. arsenal was much larger and nuclear weapon design and development was in full swing. This trend is very likely to continue for (at least) another decade: the American arsenal will shrink, there will (probably) be no new nuclear weapon developments, and the nuclear weapon budget will continue to grow (Mello 2010).

The transformation of nuclear weapons research after the CTBT

The lion's share of these new investments goes into the simulation campaign within the Stockpile Stewardship program. The aim of this campaign is an ever better ability to simulate nuclear weapons on the computer and in small and large-scale experimental settings. Thus, the loss of confidence in weapon performance due to a prolonged test moratorium should be largely compensated by the increased ability to understand nuclear weapon physics, and especially nuclear weapon ageing dynamics.

For this purpose, the U.S. DoE is bringing a number of highly expensive and very sophisticated research facilities aimed at simulating the various stages of an exploding nuclear weapon online:

1. "Hydrotesting": The Dual-Axis Radiographic Hydrodynamic Test facility in Los Alamos makes it possible to monitor the performance of both the high explosives and the plutonium pit (the so called primary of a nuclear weapon) by taking ultrafast X-ray snapshots of the imploding fissile core.
2. "Laser Fusion": The National Ignition Facility in Livermore can simulate the secondary stage of a thermonuclear weapon, i.e. the fusion of hydrogen isotopes after the primary stage.
3. "Supercomputer": The Advanced Simulation and Computing Program runs on some of the most powerful computers in the world. The aim is to optimize computer codes simulating the various stages of an exploding nuclear weapon. For this purpose the software codes will use new experimental data from hydrotesting and laser fusion, as well as the large amount of data from previous tests.

These three multi-billion-dollar technologies characterize the re-launch of nuclear weapon research after the CTBT. Fourteen years after the launch of these programs we can identify the following trends (Fitzpatrick/Oelrich 2007):

First, U.S. nuclear weapon laboratories were confident to be able to design a new warhead (the Reliable Replacement Warhead, RRW) and comply with the CTBT restrictions at the same time. Still, the RRW designs were based on previous tests, and were not entirely new designs created "freehand" on the computer. It seems therefore easier for the U.S. (more than 1000 tests) or Russia (715 tests) to develop new nuclear warheads under a CTBT than for China (45 tests) or India (3 tests).

Second: Whether virtual tests can really substitute explosive tests is a controversial subject. But it seems that countries with a large testing database (U.S. and Russia) will be advantaged in their simulation capabilities.

Third, a technology offensive as in the U.S. is less attractive for second-tier NWS. Thus, investing and relying on these replacement technologies will remain a prerogative of those NWS with a sufficiently large test database and a sophisticated nuclear weapon complex: the U.S., Russia, the U.K., France and maybe China. It will not be an option for India, Pakistan, Israel and North Korea.

Intended effects of the technology offensive

The official narrative of the technology offensive is mostly centered on the reliability and safety of the legacy nuclear stockpile during the nuclear test moratorium. Whether the trias *hydrotesting – laser fusion – supercomputing* is indispensable for this task is nevertheless disputed among experts. For example, some former weapon designers question the role of laser fusion for maintenance purposes (Kidder 1994). Others warn that conducting hydrotests "sub-critically" – as has been done after the CTBT signature at the Nevada Test Site – may yield more political costs than technological benefits (von Hippel/Jones 1996). In other words, neither laser fusion nor subcritical tests may be essential for weapon maintenance.

Still, the technology offensive may be explained by broadening the concept of maintenance: if the goal is to maintain both warheads and eggheads (i.e. weapons and weapon designers), then the addition of big science modules might make sense: first, in the absence of testing and in the light of ageing weapons, weaponeers must gain more theoretical insights in the physics of an ageing weapon. Thus, elements of basic science might advance this desideratum. Secondly, by winning the race against the ageing challenge (weaponeers learn to detect and fix ageing problems before these defects lead to performance degradation) advanced NWS might have some relative gains over their less advanced competitors: thus, with the science programs the U.S. can maintain their arsenal on higher reliability and safety standards than their less advanced competitors.

This critical effect might endanger the future of the global test moratorium, though. If the U.S. can maintain its deterrent force unscathed throughout the CTBT, and if NWS with inferior nuclear armory see their deterrent forces slowly degrading (due to their inability to perform "virtual tests" and cope with ageing problems of their weapons), then the cost-benefit analysis of the latter might tilt to the disadvantage of the CTBT.

Advocating CTBT ratification on these grounds – as some U.S. proponents do (Scoblic 2009) – may therefore backfire on the long run.

Unintended side-effects of the technology offensive

The National Ignition Facility (NIF) in Livermore, the world largest laser fusion device, is often "marketed" as a potential new energy source by its proponents. Although almost entirely funded by the nuclear weapon complex, proponents of the NIF tend to suppress the military dimension of the facility, and rather highlight its possible contribution to the global energy challenge. In principle, the NIF could lay the foundation for future commercial fusion reactors based on laser fusion.

The challenge of commercial power through laser fusion is, however, almost prohibitive, and laser fusion was not considered a viable option by the majority of sponsors of civilian fusion research. Thus, a technology like laser fusion with no chance in the (competitive) civilian energy sector might get a boost through the funding it receives through the (military) stockpile stewardship program. If we ever witness a commercial fusion reactor driven by high energy lasers, then we would have a complete reversal of the mainstream assumption that technological progress brings about new armaments and these armaments are sometimes subject to arms control. Thus, if the laser fusion reactor ever materializes, the technology dynamics would be best described by the following arrow-graph:

Arms control (CTBT) → Military replacement technology (NIF) → Civilian Technological Progress (Fusion Reactor).

3.2 Humanitarian Arms Control: Impact of the Ottawa Convention on Technological Progress

Article 2 of the Ottawa treaty defines a mine as "a munition designed to be placed under, on or near the ground or other surface area and to be exploded by the presence, proximity or contact of a person or a vehicle" and specifies that munitions designed to be detonated by vehicles and therefore equipped with anti-handling devices are not considered as a anti-personnel mines. In warfare, landmines can perform both defensive and offensive functions: When used in defense, mines are meant to protect by shaping, delaying and breaking up the movement of enemy forces or even by deterring an attack. When used in offense, mines are meant to depopulate areas and to disrupt the enemy's logistics. Beyond tactical uses on the battlefield, landmines also are used strategically in long-term missions – e.g. for the protection of facilities or borders, as in the Korean region. In the following section, we first briefly describe international efforts to control these weapons and then show how these efforts triggered technological responses.

The Ottawa treaty as an effective control instrument

After having been regarded as conventional weapons "of no particular ill repute" (Price 1998: 617) for most of their existence, the Convention on Certain Conventional Weapons (CCW, adopted in 1980)[5] was the first effort to regulate the use of anti-personnel landmines. The impulses for this treaty were given by the war in Vietnam, where anti-personnel weapons innovations (such as cluster bombs, air-delivered

[5] Long form: Convention on Prohibitions and Restrictions on the Use of Certain Conventional Weapons Which May be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects.

landmines and incendiary weapons) were tested (Prokosch 1995: 148). The CCW, consisting of a framework agreement and originally three protocols,[6] was regarded as a rather weak instrument, giving military considerations priority over humanitarian concerns (Mathews 2001: 996). So was its Protocol II that provided for the recording and marking of minefields and prohibited the indiscriminate use of landmines instead of a complete ban. Aiming to achieve the latter and to amend the Protocol II at the CCW Review Conference in 1996, in 1992 the International Campaign to Ban Landmines (ICBL) was launched. However, after efforts for an amendment in the CCW framework failed, a coalition of like-minded states and non-governmental organizations started the so-called Ottawa Process that led to the adoption of the Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction (also: the Mine Ban Treaty or the Ottawa Treaty) in 1997.[7] Today, this Convention is one of the most effective arms control treaties, having almost halted the use, the production of and the trade in anti-personnel mines (APL), clearing millions of landmines and giving assistance to many landmine victims.[8]

However, the treaty not only has not frozen technological development in the field of landmines, but rather triggered it: Because some countries – above all the United States, but also China, India, Pakistan and Russia – have declared to be unable to sign the treaty in absence of alternatives to APL, research and development efforts to close this perceived gap between military requirements and military technologies able to fill it while being compatible with the requirements of international humanitarian law have been assumed. Although in principle, the countries could have sought so-called non-materiel alternatives, that is, changes in doctrine and tactics, especially the U.S. clearly preferred a technological solution, thus initiating a number of programs searching for substitutes for landmines. Since the U.S. is leading – though not the only one – in this field, in the following, its landmine policy will be described with a focus on R&D programs undertaken as a reaction to the landmine ban.[9] Subsequently, some of the alternatives under discussion will be presented and finally, their conformity to the landmine treaty and their assumed humanitarian impact will be discussed.

U.S. policy on landmines: acknowledging the problem, refusing to sign the treaty and seeking for technological solutions

The United States are not only the leader in the search for technological responses to the landmine problem – they have also been one of the leading countries pointing to the humanitarian catastrophe caused by landmines and taking action to cope with it. As

6 Protocol I on fragments non-detectable by X-rays, II on landmines and booby traps and III on incendiary weapons; Protocol IV prohibiting blinding laser weapons was added in 1996, Protocol V on Explosive Remnants of War in 2003.

7 The Convention entered into force in 1999 and has 156 state parties today.

8 According to the Landmine Monitor 2009, only two states (Russia and Myanmar) are still using landmines and the use by non-state armed groups is declining as well; 38 states have stopped to produce APL, 13 still do so; there is almost no legal trade in APL, 86 States Parties have completed the destruction of their stockpiles, having destroyed about 44 million APL.

9 Especially some European countries (Germany, UK and France), but also Australia and Japan, have started R&D programs to explore alternative technologies to landmines, mostly focusing on systems based on electric sensors and remote controls (Landmine Action 2001: 115-116).

early as 1992, under the presidency of George Bush Sen., the U.S. Congress adopted a national export moratorium on APL (in December 2007, the ban was extended until 2014). On the international level, Bush's successor Bill Clinton emphasized the US´s support and commitment to pursue an international ban – however declared in September 1997, that the U.S. will not sign the Ottawa treaty as it would put their soldiers at risk: "As Commander in Chief, I will not send our soldiers to defend the freedom of our people and the freedom of others without doing everything we can to make them as secure as possible" (quoted in the New York Times, 18.09.1997). Behind these concerns about the security of U.S. soldiers, the reasons for the U.S. refusal to join the Mine Ban Convention are threefold: The treaty would have required the U.S. to remove their APL from the demilitarized zone between the North and the South Korean border; it would not only have banned their APL, but also so-called mixed systems consisting of anti-tank mines and anti-personnel mines; and the treaty did not include a transition period which the U.S. perceived as necessary to devise alternatives (Capece 1999: 184, National Research Council 2001: 15).

While refraining from formal adherence to the treaty, the U.S. however emphasized its commitment to solve the problem of APL – considering technological solutions as an alternative way to the ban approach taken in the Ottawa process (Capece 1999: 187). In 1996, even before the process began, President Clinton announced plans to actively pursue the development of alternatives to APL and directed the Under Secretary of Defense for Acquisition and Technology to initiate a corresponding program. Expecting these efforts to be successful, the President also promised that the U.S. would end the use of self-destructing mines by 2003, find substitutes to the mines used in the Korean region – and thus be able to sign the Convention by 2006 (Washington Post 31.10.1997, The Lancet 2001: 731). The Bush administration, while upholding the export ban and research activities, in parts revised the mine policy of the United States by withdrawing the promise to join the treaty and permitting the use of self-destructing mines indefinitely (Human Rights Watch 27.2.2004). Moreover, the deadline for the use of long-lived antipersonnel mines along the Korean borders was postponed until 2010 – after that date, the U.S. committed to cease the employment of such persistent APM (Crook 2008: 190). The Obama administration's first review of the U.S. landmines policy led to the decision to stick to the line of its predecessors and not to sign the treaty. Nevertheless, the State Department reacted to pressures from Congress and activist groups and promised to conduct a comprehensive review of the issue (Washington Post 8.5.2010). It was initiated in late 2009 and is still ongoing.

Three tracks to search for alternatives: Eliminating victim-activation or lethality

The plans to find adequate technologies to replace landmines have been motivated by several factors: 1) the humanitarian problem caused by anti-personnel landmines and the hope to contribute to its solution technologically, 2) the attempt to find more effective weapons than the available APL and 3) to extend the lead in the field of landmine technologies (National Research Council 2001: 2, Sprowls 2001: 56).[10]

[10] Some statements of the Army suggest that the Mine Ban has been perceived as in the interest of the U.S. because it promised to eliminate a low-technology and low-cost weapon using

Searching both for innovations and for possibilities to integrate existing technologies into new systems, the U.S. Department of Defense pursued three tracks, each with a different goal:[11] Track I focused on the protection of the South Korean border and thus had the goal to find alternatives to the non-self destructing land mines used there. It consisted of two programs – the NSD-A (Non-Self Destruct Alternative) and RADAM (Remote Area Denial Artillery Munition).[12] After almost 100 million USD had been spent on these technologies and the first prototypes of the NSD-A were produced, funding was cancelled by the Army in 2002. Track II focused on long-term, technologically advanced solutions to maneuver-denial and was put under the direction of the Defense Advanced Research Project Agency (DARPA). It developed the so-called Self-Healing Minefield – a system of "intelligent", networked and self-repositioning anti-vehicle mines that was fully tested in 2003. Although the system does not rely on anti-personnel mines, it is activated by vehicles and thus unable to discriminate between military and civilian targets. Track III, which has been provided funding by the Congress in 1999, overlaps Track I and Track II. It aims at the development of *lethal, but non-victim activated* or *victim-activated, but non-lethal* weapons or weapon systems that may serve as alternatives to landmines.

- Lethal, but non-victim activated systems: Introducing weapons that are not activated by the victim but require an identification by the soldier and his conscious decision to engage a target with a lethal mechanism was one attempt to eliminate the non-discriminating effect of anti-personnel landmines, this being the main reason for their prohibition. Such "man-in-the-loop" systems must include three components: a real time surveillance system to automatically detect and classify the objects; command and control systems to immediately react if the object has been identified as an enemy force and precise firepower to hit the object (Landmine Action 2001: 41). One such system, resulting from the Track I NSD-A, is the SPIDER system consisting of a web of tripwires across an area, hand-emplaced munitions and a control unit monitoring them – once the operator receives the signal that a tripwire has been touched, the munitions can be activated. First, SPIDER was planned to include a victim-activated mode but after this feature had been criticized to be incompatible with the Mine Ban Treaty, the Army announced in May 2008, that SPIDER will be produced in a version that only allows for command-detonation (Landmine Monitor 2008).
- Victim-activated, but non-lethal systems: The non-lethal weapons doctrine resulted from the perceived need of the U.S. to operate in missions where civil and military targets could not be targeted separately and thus it was necessary to limit the effects

which "the least technically developed combatant can compete with the most developed adversary" (Sprowls 1999: 56, referring to May 1998: 1).

11 Descriptions of the tracks are based on Landmine Action 2001, National Research Council 2001, Feigenbaum 2000, Landmine Monitor 2004, Human Rights Watch 2000, 2001.

12 Both projects were criticized to include elements that were prohibited by the Mine Ban Treaty: Although the NSD-A munition was planned to be activated by a remote operator who would send a fire command to the munition after having received a signal of intrusion, it is also reported to having had a victim-activated feature. RADAM combined existing anti-personnel mines ADAM and anti-vehicle mines RAAMS into a mixed system and thus, could not be considered as an alternative but rather as a "just another landmine program" (Colonel Paul Hughes, quoted in Feigenbaum 2000).

of the and to ensure the recoverability of the victims from the attack (Landmine Action 2001: 8). While the non-lethal weapons program includes a broad range of weapons and is not limited to APL alternatives, some of the weapons under consideration are meant to have similar functions as APL – e.g. incapacitating individuals to hinder them to enter an area, stopping vehicles, and controlling the movement of crowds (or forces). To produce these effects, several materials and instruments are taken into account: for example calmatives or obscurants that are released from a devise after it is stepped on, entanglements such as slippery substances and nets, acoustic mines issuing sounds to incapacitate the victim and electric weapons, such as Taser Area Denial Devices, incapacitating the victim with electroshocks.

Criticism of alternative weapons

While generally approving the efforts to develop substitutes for non-discriminatory anti-personnel mines, humanitarian organizations have, however, critically commented on the concrete technologies under consideration for several reasons. First of all, they are perceived to draw a distinction between acceptable, since technologically advanced, mines on the one hand and to blur the distinction between mines and other weapons on the other. Furthermore, several systems (like RADAM and earlier versions of SPIDER) have been labeled alternatives to APL while including similar components and thus, capable to produce landmine-like effects. Doubts also exist whether man-in-the-loop systems can really pose a reliable solution to the problem of discrimination, since it may not always be possible for the commander operating from remote to clearly identify and classify the intruding object. The focus on non-lethal weapons is subject to criticism as well: the label "non-lethal" is not based on independent criteria but is usually assigned by the manufacturers of the weapons and meanwhile, several examples are known where so-called non-lethal weapons have caused lethal effects.[13] Moreover, the doctrine behind these weapons explicitly includes civilians as their targets – even if they are not killed, they are harmed physically and psychically. While pointing to problematic aspects of technological reactions to the Ottawa Convention, organizations like Human Rights Watch recommend exploring non-materiel options as well, that is reconsidering strategy and tactics.

4. Conclusion

The U.S. policies toward the CTBT and the Ottawa Convention show some striking similarities and display a disturbing trend: it seems that in order to be able to ratify a treaty addressing the reduction, limitation or elimination of a certain type of weaponry, Washington must unleash a new technology offensive in a related branch of armory. Within this logic, arms control and disarmament in one branch of military technology correspond to new investments in other military technologies.

We assume that these dynamics can be explained by overlapping two contrasting narratives: on the one hand the U.S., as a "good international citizen", feels the heat as more and more states ratify the CTBT and the Ottawa Convention. Thus, normative pressure induces Washington to work towards ratification of these treaties. On the other hand, the military logic demands some compensation, if military missions and doctrines are not subjected to some revision, as well.

If arms control does not come with a change in doctrines, then it can lead to new destabilizing armament dynamics. It can trigger new arms races in unregulated fields, e.g. in the field of non-lethal weapons or in the domain of non-victim activated systems. In principle it also can trigger new nuclear arms races, where the simulation programs replace ordinary nuclear tests. In its most extreme manifestation the dynamics we describe can lead to the collapse of an arms control regime: In the case of the CTBT, the insistence of the U.S. that it can upgrade and maintain its nuclear arsenal at the highest levels due to its unparalleled technical investments, might irritate less advanced NWS. They might fear a widening technological gap between their nuclear arsenal and the arsenal of the leading NWS, and may reconsider their adherence to a global nuclear test ban. Similar considerations might hold for the Ottawa Convention: less advanced states simply will not have the resources to invest in "replacement technologies" and might reconsider reverting to "classical" APL during a conflict or a prolonged crisis.

For disarmament advocates it is not easy to criticize these dynamics, as a State might point to its good faith to advance the global arms control agenda: gathering domestic support for an arms control treaty – pragmatists would argue – requires substantial compensations for those political fractions, which are deeply skeptical about restraining, limiting or eliminating some of their military capabilities (Isaacs/Gard 2010). Still, another reading of these bizarre armament dynamics is possible: states can easily justify increasing defense budgets, especially in the field of research and development. Thus, a state interested in specific new military technologies can appease criticism, if the R&D takes place in the context of a wider arms control or disarmament framework. In this light, it is remarkable how a steadily growing nuclear weapons budget meets little criticism in the U.S. (and outside), since President Obama has been seeking to advance a global nuclear disarmament agenda. It should be noted that (domestic) criticism of U.S. ballistic missile defense (BMD) plans has grown silent as well, since Obama put BMD in the context of Global Zero, the vision of a world without nuclear weapons.

From our case studies we can derive pessimistic and (slightly more) optimistic generalizations. A pessimistic conclusion would emphasize the Sisyphus-like work represented by attempts to control international armament dynamics: the prohibition of one type of weapon will lead to the development of some replacement technology, which can execute the same military mission as its predecessor. Although allegedly being less lethal or less cruel, alternative weapons still remain weapons and thus, are designed to kill or injure – this might be easily obscured by the humanitarian motives apparently leading to their development.

A slightly more optimistic narrative might emphasize that the replacement technologies still are a better alternative to the status quo ante: virtual nuclear tests don't have the same disruptive political effects as explosive tests, and non-lethal area denial systems might be preferable to ordinary APL. Furthermore the investment in new replacement technologies might give unexpected results, which could be beneficial in the civilian context on the long run, e.g. a new commercial fusion reactor.

In the light of this complex dialectics between the control and the acceleration of armament dynamics the big question on the future of arms control arises: how can arms control lead to an effective restraint in the use of force and to a diminished level of (effective and potential) violence? The concept of preventive arms control points into the right direction, as it emphasizes the necessity to identify potentially destabilizing technological innovations at an early stage. Our examples demonstrate the necessity to expand this precautionary principle to alternative technology trajectories, which might unfold within the arms control process. Therefore, vigilance already during the negotiation process is of utmost importance in order to minimize technological loopholes; following the idea of preventive arms control, this vigilance should preclude certain technological developments and make sure that arms control agreements will be both durable and (ever more) compatible with the humanitarian norms of warfare.

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