Michael Brzoska

Trends in Global Military and Civilian Research and Development (R&D) and their Changing Interface

Executive Summary

Until very recently, global military R&D had been in decline for some time, in terms of overall spending. The main reason was the end of the Cold War, which led to a virtual collapse in the former Soviet Union and substantial reductions in many other countries. This left the United States as the largest spender worldwide by a large margin. Increases in US spending in the late 1990s and early 2000s have further widened the gap to the rest of the world. The US accounted for more than 60 percent of global spending on military r&d of an estimated US $85 bn in 2004.

Already prior to the decline in absolute numbers, military r&d had declined in relative importance due to major increases in civilian r&d. Even in the US, civilian spending is now substantially larger than military spending. In global terms, civilian r&d is about 10 times as large as military r&d. Most of the civilian r&d is privately funded. The largest private r&d spenders, large companies, have higher r&d budgets than governments can muster for military purposes, with the exception of the United States. While a good part of civilian r&d is in sectors of lesser relevance to the military, much occurs in technology lines important for the production of military goods. In general, the differences between civilian and military technology lines have shrunk.

Not least because of the growing importance of civilian r&d, military r&d has seen major structural changes, in most countries. There has been a major shift towards military use of technologies driven by civilian r&d, particularly in electronics. Also, the success of civilian technology production has fostered the move away from a particular military culture of technology generation.

Traditions, national technology cultures but also differences in the relative importance of military and civilian r&d among countries are reflected in various policy approaches, which range from isolation of military r&d, trusting that it will provide top-level technology, to civilian r&d-led approaches limiting the role of military r&d to filling gaps left by military r&d. Shifting trends in the relation between civilian and military r&d have induced some governments, in particular the US, to policy changes. However, the most recent policy adopted in the US seems to run counter to the approaches of acknowledging and exploiting the growing importance of civilian r&d. It remains to be seen whether the greater reliance on military r&d noticeably in the US will prove effective and efficient, both in terms of the development of new military and civilian technology.

Introduction

Issues related to civilian and military research and development (r&d), including their interaction, are highly contested. Some have viewed military research and development as a very, if not the most important, source for the development of new civilian technology, citing, as examples, technologies coming out of World War II, such as radar, the electronic computing, game-theory or the container. Others are highly critical of the effectiveness of military technology to produce things for civilian use, and instead claim that military demands have stifled civilian research[1].

In this paper, I argue that both views are partially correct. Military r&d is not primarily geared towards civilian applications, but will produce them anyways. Military and civilian r&d are often complementary but are also competing with each other, for attention, resources and brains. Accepting the potential of mutual benefit of civilian and military r&d opens a wide variety of questions, such as which of the two sectors is leading in which areas of knowledge and technology, whether and what kind of transmission of knowledge and technolgy exist between the two sectors and how policy can affect the flow.

I will look at these questions in turn. In particular, I will argue two points:

- First, the relation between civilian and military r&d has changed over time (I am restricting myself to the last 50 years or so, not being a historian), with civilian r&d growing in importance both for the production of civilian and military technology. In the new century, civilian r&d is overwhelmingly important in producing both civilian knowledge and technology. The main reason for this are relative quantities of funding, however, there are also qualitative or structural reasons.

- Second, I will argue that decision-makers over both the spending on r&d and resulting products in the leading countries, particularly the United States, are currently out of step with these changes, resulting in suboptimal decisions on the exploitation of the civilian/military interface, but also the procurement of defence technology. Main reasons here, in my view, are vested interests, of r&d establishments, defence producers and acquisition bureaucracies, but also a kind of built-in conservatism of military forces. There is not, and has never been, one single model of civilian/military interaction, and what may be good or

[1] For overviews see e.g. Gummett and Reppy, 1988; Gummett et al, 1996.

bad choices for a country in particular circumstances may not be relevant for a country in other circumstances. I will limit my remarks to the major industrial countries.

The paper has four sections. The first one is a broad-brush summary of trends in the quantities of civilian and military r&d. The second section focuses on some structural elements of the changing interface between civilian and military technology, namely the rise of civilian r&d. The third section outlines a framework for the analysis of the relation between civilian and military r&d. The final substantial section looks at a selection of policy approaches to the generation and exploitation of civilian/military interaction.

1. Overview over r&d trends

1.1. Current global military research and development efforts

Global spending on military r&d amounted to about US$ 85 billion in 2004 (Figure 1). This is a quite impressive figure even if one considers that more than 60 percent of that sum was spent by the US government.

However, this figure was small if compared to global spending on civilian r&d, which amounted to about US-$ 850 billion in 2003[2].

The ratio between civilian and military spending differs widely among countries. Unfortunately we do not have reliable data for most countries. The best data available are for OECD member countries. Even for this fairly homogenous group we have a wide variance of ratios (see figure 1), ranging from less than 1 percent in the case of Japan to more than 17 percent in the case of the United States. For Russia, an even higher estimate is plausible.

---

[2] This rough estimate includes both OECD and select non-OECD member countries.

Figure 1: Data on global military and total r&d, 2004

	Total R&D expenditures, in US $ billion	Share of business financed R&D in total, in %	Share of public financed R&D in total, in %	**Military R$D expenditures in US $ billion**	Share of military R&D in total R&D, in %	Share of military R&D in public R&D, in %
France	**39.7**	51	39	**3.5**	9	23
Germany	**58.7**	67	30	**1.0**	2	6
Italy	**17.7**	43	51	**0.4**	2	4
Japan	**112.7**	75	18	**1.0**	1	5
Korea	**24.3**	74	24	**0.8**	3	13
UnitedKingdom	**33.7**	44	31	**3.4**	10	32
United States	**312.5**	64	31	**54.1**	17	56
EU-25	**211.3**	**54**	**36**	**11.2**	**5**	**15**
Total OECD	**686.7**	**62**	**30**	**69.7**	**10**	**33**
China	**102.6**	60	30	***5.0***	*5*	*16*
Russian Fed.	**16.5**	31	61	***4.0***	*24*	*40*
Israel	**5.0**	64	29	***1.5***	*30*	*100*
Other Non -OECD	***40.0***			***4***		
World	**850.0**	***60***	***31***	***85.0***	***10***	***33***

Note: *Italic*: own estimate, based on estimates for military expenditures and arms sales, data taken from SIPRI Yearbook 2006, Oxford: Oxford University Press 2006

Source: OECD, Main Science and Technology Indicators, 2005/2, Paris; Israel: European Commission, Key Figures 2003-2004, Brussels 2005 http://cordis.europa.eu/indicators/-publications.htm; military expenditures: SIPRI Yearbook 2006.

Military r&d spending is largely, though not exclusively, funded by national governments. Globally, as for the group of OECD member states, one third of all public spending on r&d is for military purposes. This ratio is strongly influenced by the spending patterns of the United States, which is not only, by far, the largest spender on military r&d, but also on public r&d in general. Still considerably more than 50 percent of all public r&d spending in the United States has been for military purposes. Other countries with high ratios of military to civilian r&d include Russia and Israel. In both countries, funding of r&d has additional sources to the national government sector. For Russia, funding by national defence companies, out of arms sales proceeds, has probably been on a similar scale, if not higher, than government spending. In addition, there is some direct funding from foreign companies and governments. In Israel, the main source for r&d funding has been external, through US military assistance and by foreign companies as well as governments.

Except Russia and Israel, it seems that fairly little funding of military r&d comes from private sources, though we lack qualified data on this topic. The OECD, for instance, only collects data for government funded military r&d. Data collected on companies, for instance by the British Department for Trade and Industry (DTI) tends to exclude at least some parts of r&d funding by defence companies.

1.2. The growing importance of civilian r&d

While 10 percent of global r&d is for military purposes, 90 percent is for civilian purposes. One expression of the overwhelming importance of civilian r&d is that the r&d investments of a good number of companies are larger than the military r&d efforts of almost all governments worldwide. The only exception is the United States (see Figure 2).

Figure 2: Trends in global military r&d, 1996-2004

Military r&d expenditures in US $ billion, prices of 2004

	1996	**2000**	**2004**
France	**4,6**	**3,2**	**3.5**
Germany	**1,9**	**1,5**	**1.0**
Japan	**1,2**	**0,9**	**1.0**
Korea	**1,3**	**1,2**	**0.8**
United Kingdom	**3,9**	**4,1**	**3.4**
United States	**44,7**	**42,4**	**54.1**
EU-25	**12,9**	**11,3**	**11.2**
Total OECD	**60,3**	**57,0**	**69.7**
China	***2,7***	***3,8***	***5.0***
Russian Federation	***0,8***	***2,5***	***4.0***
Israel	***1,3***	***1,3***	***1.5***
Other Non –OECD	***4***	***4***	***4***
World	**69**	**69**	***85***

Note and sources see figure 1.

The balance between civilian and military r&d has shifted gradually over time. We lack good global data, however, the example of the United States, the largest spender on public r&d worldwide, is instructive (see figure 3).

Figure 3: Top 10 global companies by R&D investment, 2004/2005

Company	R&D investment in US $ bn	Sales, in US $ bn	Employees
Pfizer	7.7	27354	115000
Ford Motor	7.4	89407	324864
General Motors	6.5	100795	324000
Microsoft	6.2	20724	61000
DaimlerChrysler	7.7	100573	379019
Toyota Motor	7.4	94298	265753
Siemens	6.9	53216	419200
Matsushita Electric	6.0	44292	334752
IBM	5,7	50155	329001
Volkswagen	5,7	62983	321090

Source: DTI International R&D Scorecard, http://www.innovation.gov.uk/rd_scoreboard/.

Over the last 50 years, total r&d funding has grown tenfold in the USA. At the same time, military r&d has grown by a factor of 4 from around US$ 14 bn US in 1953 to around US$ 55 bn in 2003 (in constant prices of 2000). Much higher growth, however, can be noted for civilian r&d, from about US-$ 15 bn to over US-$ 200 bn. Thus the parity between military and civilian r&d of the 1950s and early 1960s has given way to a clear dominance of military r&d in the USA, which, as noted above, maintains one of the highest rations between military and civilian r&d in the world.

Figure 4: U.S. inflation-adjusted R&D expenditures, by source of funds and performing sector, 1953–2004

Costant prices of 2000

	Funding share. in %			Share of military r&d in federalr&d outlays, in %	Defense r&d	Total r&D
	Federal	Industry	Others		In billion US $	
Year						
1953	53.9	43.5	2.5	84	12.8	28.3
1954	55.2	42.3	2.6	84	14.1	30.5
1955	57.4	40.2	2.5	82	15.8	33.5
1956	58.6	39.4	2.1	82	21.1	43.8
1957	62.9	35.0	2.1	79	24.6	49.4
1958	63.9	34.0	2.1	77	26.2	53.2
1959	65.4	32.5	2.1	84	33.1	60.2
1960	65.0	32.9	2.0	81	34.3	65.2
1961	65.1	32.7	2.2	79	35.2	68.5
1962	64.8	32.8	2.4	72	33.8	72.5
1963	66.5	31.1	2.4	63	33.7	80.4
1964	66.8	30.8	2.4	57	32.9	86.3
1965	65.1	32.3	2.5	51	29.8	89.9
1966	64.2	33.2	2.6	48	29.3	95.2
1967	62.4	34.9	2.7	51	31.1	97.7
1968	60.7	36.5	2.8	53	31.9	99.0
1969	58.6	38.5	2.9	53	30.9	99.4
1970	57.0	39.8	3.2	53	28.8	95.4
1971	56.4	40.2	3.4	53	27.9	93.2
1972	55.8	40.8	3.4	54	28.7	95.3
1973	53.6	43.0	3.4	54	28.1	97.2
1974	51.8	44.6	3.6	54	26.9	96.1
1975	52.0	44.4	3.7	52	25.4	93.9
1976	51.5	44.9	3.7	49	24.8	98.1
1977	50.9	45.3	3.7	47	24.3	101.4

1978	50.1	46.1	3.8	51	27.2	106.5
1979	49.2	47.1	3.7	49	26.9	111.8
1980	47.4	48.9	3.7	46	25.5	117.0
1981	46.7	49.7	3.6	48	27.4	122.2
1982	46.0	50.4	3.6	50	29.6	128.8
1983	46.1	50.3	3.6	57	36.3	138.0
1984	45.5	51.0	3.5	62	42.6	151.1
1985	45.9	50.5	3.5	63	47.6	164.5
1986	45.4	50.7	3.9	64	49.0	168.8
1987	46.4	49.5	4.1	68	54.5	172.6
1988	44.9	50.8	4.3	70	55.6	176.9
1989	42.6	52.8	4.6	68	52.3	180.6
1990	40.5	54.7	4.7	66	49.8	186.3
1991	37.8	57.4	4.8	64	46.1	190.5
1992	36.8	58.2	5.0	61	43.0	191.4
1993	36.5	58.3	5.2	59	40.4	187.5
1994	35.9	58.6	5.5	59	39.7	187.5
1995	34.3	60.4	5.3	57	39.0	199.4
1996	32.1	62.5	5.3	55	37.1	210.3
1997	30.4	64.2	5.3	58	39.2	222.3
1998	29.2	65.5	5.3	57	39.3	236.0
1999	27.4	67.2	5.4	55	37.7	250.3
2000	24.8	69.7	5.5	54	35.8	267.2
2001	26.3	67.9	5.8	56	39.9	270.8
2002	28.2	65.5	6.3	55	41.1	265.0
2003	29.7	63.9	6.4	57	46.6	275.3
2004	29.9	63.8	6.3	57	49.2	288.4

Sources: United States National Science Foundation Science and Engineering Indicators 2006, Washington, DC, 2006, http://www.nsf.gov/statistics/seind06/append/c4/at04-03.pdf; United States Governemnt, Budget for FY 05, Historical Tables, Washington, DC 2004, Table 9.7, http://www.gpoaccess.gov/-usbudget/fy05/hist.html

By far the most important reason for this trend has been the growth of industry funded r&d. Federal r&d has also grown substantially over the years, though much slower than privately funded r&d, resulting in a dramatically reduced share of federally funded r&d in total r&d in the USA since the mid-1960s from over 60 percent in the late 1950s and early 1960s to less than 25 percent in 2000. Since than it has begun to grow again, to a level of almost 30 percent. While the share of military r&d in federal r&d has remained very high by international standards, the decline of the share of public funding in total funding has led to a relative decrease in the importance of military r&d in the United States, at least until very recently.

In other OECD member countries, the trend has been even more pronounced (see figure 4): While for the US the military share in total r&d has declined from 25 percent to about 16 percent between 1981 and 2003 according to OECD data, for other OECD member states the decline has been much more pronounced, from 9.3 percent in 1981 to 3.0 percent in 2002. These countries experienced even larger increases in privately funded r&d than the USA.

1.3. Consequences of the shift in r&d funding

Some of the consequences of the relative increase in nondefense r&d will be discussed below. Here only a few observations from the available data will be made.

The defense and aerospace sector, which was once seen as the epitome of the search for new knowledge, is, according to available data, not among the most research intensive industry sectors any more. Data collected by the British Department for Trade and Industry (DTI) for the top r&d investing companies, for instance, show this sector to lag behind the pharma and biotech and health industry, but also IT hardware, and electrical and electronic industry (see figure 5). While some of these industries may in fact also perform defense-related work – placing companies into industrial sectors is notoriously deficient – the data, despite some shortcomings, seems to clearly reflect the loss of r&d leadership of the defense sector which can also be seen from other statistics.

Figure 5: Share of military r&d in total r&d, 1981-2002, in %

	United States	OECD countries excl United States	OECD member countries
1981	25.3	9.3	17.0
1982	28.3	8.6	18.1
1983	29.5	8.0	18.5
1984	30.4	8.2	19.3
1985	31.1	7.5	19.2
1986	31.5	7.4	19.3
1987	31.8	6.8	18.8
1988	30.6	6.0	17.7
1989	28.2	7.1	17.0
1990	25.5	6.4	15.1
1991	22.6	5.8	13.3
1992	21.8	5.9	13.0
1993	21.8	5.9	12.9
1994	19.7	5.6	11.7
1995	19.0	4.9	11.0
1996	17.4	5.0	10.5
1997	17.0	4.5	10.0
1998	16.2	4.5	9.8
1999	14.6	4.0	8.8
2000	13.7	3.6	8.2
2001	13.9	3.3	8.0
2002	15.6	3.0	8.5
2003	16.6		

Source: United States National Science Foundation Science and Engineering Indicators 2006, Washington, DC, 2006, http://www.nsf.gov/statistics/seind06/append/c4/at04-03.pdf.

Are there also consequences for research output? Based on the empirical evidence of the relative gains in terms of civilian technology (see e.g. Glissmann/Horn/Schrader, 1993) one would expect to see an improved efficiency of total r&d in the production of civilian knowledge because of the shift in composition in r&d. Although defense-related r&d does result in spillovers that produce social benefits, nondefense r&d is more directly oriented toward national scientific progress, standard-of-living improvements, economic competitiveness, and commercialization of research results. A number of past studies have confirmed this effect, which however does not seem to be overly large over long period of time, but changing over time. Figure 6 shows no clear pattern in the variance in performance indicators among countries with relatively high or relatively low shares of military r&d in total r&d. More important seem to be science styles and national systems of innovation to link research efforts to outputs (Nelson, 1993; Larédo and Mustar, 2001).

Figure 6: Research intensity of the top 1000 global companies by R&D investment by industrial sector, 2004/2005

Sector	R&D investment in US $ bn	Share of R&D in Sales, in %	R&D per employee , in 1000 US $
Pharma & biotech	76.8	15.0	30.3
IT hardware	78.7	8.6	14.6
Health	8.5	6.6	8.1
Electronic & electrical	47.7	5.5	7.2
Aerospace & defence	16.1	4.9	6.9
Automobiles & parts	80.1	4.3	8.7
All companies composite	**424.1**	**3.8**	**7.3**
Chemicals	21.4	3.7	8.3
Engineering & machinery	12.5	2.5	3.7

Source: DTI International R&D Scorecard, http://www.innovation.gov.uk/rd_scoreboard/.

2. Shifts in military r&d

The lack of much systematic difference between military and civilian r&d efforts in figure 6 is an indication of growing similarities between civilian and military r&d with respect to both process and performance in many countries.

2.1. Changes in structural factors

In the past, military r&d was largely kept separate from civilian r&d. The epitome of this were the Russian “Naukograds”, fenced cities for military science. While the barriers between civilian and military r&d have not broken down, and are in fact partly re-erected in some countries, see below, some factors that made military r&d distinct in the past (Alic et. al., 1992, pp. 43-44; USOTA, 1993, 1994, pp. 5-6) have lost in relative importance. These include:

- *Secrecy requirements*. These lead to the compartmentalization of research and add a heavy layer of bureaucracy to research work. While secrecy still looms large, the end of the Cold War has reduced its pertinence at least in some countries. Demands for better control, for instance by parliaments, have also put pressure on secrecy provisions.
- *Performance orientation*. Research and development in the military field has traditionally been guided by requirements for the fulfillment of technical criteria, which often were only reached by pushing the frontiers of knowledge outward, at high cost. Increasingly, however, cost consciousness has increased also in the defense industry, changing the framework for military r&d.

With reduced levels of secrecy, lesser emphasis on performance orientation and more cost consciousness, the '*defense research culture*' which marked military r&d during the Cold War, has lost some of its pertinence. The earlier separate world of high quality research facilities, above-average financial remuneration and stable labor relations has at least somewhat been brought back into the realm of "normality" (Markusen and Costigan, 1999).

2.2. Sectoral shifts

Another feature changing military r&d and its relationship to civilian r&d has been the rise of, first electronics, and second, systems integration in defence production.

The rise of electronics began already in the 1970s. On all levels, from weapon system to central command organisation, communication was modernised, command and control was broadenend and centralised, reconnaissance, surveillance and target acquisition were enhanced. This resulted in a relocation of r&d and procurement spending, away from traditional weapon platform and weapon system producers and towards electronics and computer companies. Many of these companies and r&d establishment had had little contact with the military sector before and were not part of the "defence industry culture" (Misa, 1980).

Beginning in the early 1990s, a new trend was discernable (US OTA, 1994; Gansler, 1998). Traditional weapon integrators had acuired sufficient capabilities in electronics and information technology, often through acquistions, to be able to satisfy demand. They increasingly turned into system integrators, linking various industrial sectors, including electronics and information technology. They adopted a range of r&d styles, generally less rigid than what had been the norm in defense industry before.

2.3. Privatization

Military r&d is predominantly government-financed but only partly performed in the government sector. While much of r&d performance, particularly on the d-end, was performed in private enterprises in some countries, such as Germany and the USA, already in the 1960s, other countries kept most of r&d spending in the public sector, giving the money to government research institutions and government-owned companies. The 1980s and 1990s saw major change in this respect. In the United Kingdom, Italy, Sweden and France, for instance, publicly-owned companies were privatized, and large government research establishment reorganized and reduced in size. The most drastic change occured in the UK, where the largest single defense research organisation in the Western World, the UK Defence Evaluation and Research Agency was divided up, leading to the establishment of QinetiQ. QinetiQ is offering its services to both commercial and military customers worldwide. It was recently introduced at the London Stock Exchange (http://www.qinetiq.com/home/aboutqq.html).

Privatization does not necessarily lead to changes in "defence industry culture". As has been shown by numerous examples, private companies, can operate at high levels of secrecy, optimize performance and work with little cost-consciousness. However, particularly when they also have private customers, will they tend to not adopt such a style but rather work like other commercial companies US OTA, 1997; Gansler, 1995).

3. Dynamics of civil-military interaction

3.1. Elements of civil-military interaction

Military/civilian interaction in r&d can be found on various levels.

One familiar way to look at the interaction is along the research-development-product continuum. The conditions under which basic research is conducted are often not much different from those in which civilian research occurs. Secrecy requirements, however, may still put high barriers between civilian and military basic research. Also, the mix of scientific disciplines in military and civilian research differs with physics (including nuclear physics in the nuclear weapon states), material sciences, telecommunication, aerospace and space research, and information sciences dominating military research. Differences in objectives, and thus in the generation of technologies, generally increase as one nears the development of weapon systems. To give just one example, diesel engines for tanks are functionally not different from engines for trucks. On the other hand, tank engines are optimized to be small, light-weight and produce much power, while for truck engines, fuel consumption levels and serviceability are very important. Military and civilian technology development therefore tend to partly go in different directions, but partly also to be compatible. Linked to this are the issues of spin-off of military technology for civilian use, and spin-in of civilian technology for military use.

This traditional look at civilian/military interaction emphasizes the similarity or difference of outputs of r&d funding. The aim is to look for research results, technologies and technolgy applications with dual civilian-military use (Cowan and Foray, 1995; Kulve and Smit, 2003). While this is an important element of the civilian/military interaction, it ignores other elements. A broader look at civilian/military interaction (see figure 7) includes:

- Production factors of knowledge and technology generation, such as scientist, but also research infrastructure. The degree of transferability of production factors between civilian and military r&d is influenced by a number of factors, including differences in technologies and secrecy requirements. It can range from almost zero, for instance for scientists specialising on ballistics, to full substitutability, for instance when civilian and military r&d is peformed simultaneously in the same laboratory.
- Know-how of technology generation, such as research methods and test procedures, as well as production methods. Again, differences in methods for knowledge and technology production between civilian and military r&d know may be large or small, depending on a number of factors.
- Funding of knowledge and technology generation. Once it is acknowdeged that technology developed in the civilian sector has military applications and vice versa, funding issues become relevant: civilian technology is not only funded by civilian r&d spending, and military technology is not only funded by civilian r&d. The extent of such de facto cross-sectional funding will again depend on differences among technologies. In addition, primary performance objectives also have an effect, with military funding overproportionally

important for risky technologies[3], and civilian funding overproportionally important for improvements in cost savings, including in production methods.

3.2. Changes over time in civilian/military interaction

Financial and structural factors have combined to reduce the importance of military r&d relative to civilian r&d over time. This refers to all levels of knowledge and technology production. In principle, civilian know-how production and technology development is dominant. Those domains, where military r&d, with its particular funding and specific "culture", is in the lead have diminished. These still include:

- Knowledge and technology with little or no civilian use
- Funding of risk technologies.

The trend of decreasing importance of military r&d for the knowledge and technology generation has been more or less uniform over the last half century or so. However, its acceptance and manipulation by policy makers has differed over time and by country. An overview over some of the policy approaches to civil-military interaction follows.

[3] There are many examples of technologies invented in the civilian sector, nurtured in the military sector, and later mass-used in the civilian sector, such as jet engine propulsion, the transistor and integrated circuits.

Figure 7: R&D performance expenditures, by source of funds and performing sector: 1953–2004

	Total R&D expenditures, as share of national income, 2002, in %	Scientific publications per million inhabitants, 2002	Patents per million inhabitants (EPO and USPO), 2002	Share of country in global R&D, 2002, in %	World market share of exports of high-tech products, 2001, in %
Israel	4.8	1334	141	0.6	0.6
Japan	3.1	550	208	13.3	8.9
United States	2.9	774	203	36.8	18.8
Germany	2.5	731	198	6.9	8.1
France	2.2	726	95	4.7	7.4
EU-25	2.0	673	84	24.9	37.5
United Kingdom	1.8	1021	78	4.0	6.5
Italy	1.1	545	48	2.1	1.9

Source: Calculated from European Commission, Key Figures 2003-2004, Brussels 2005. http://cordis.europa.eu/indicators/publications.htm.

4. Policy approaches to civilian/military interaction

Various governments have chosen differing strategies and set distinct priorities on civil/military r&d interaction. In most cases, these have differed over time, reflecting the changing dynamics of civil/military r&d interaction but also the influence of interest groups. Five policy approaches are discussed below as 'ideal types' (see also figure 8). In practice, governments often support mixtures of these styles.

'Spin-off' approach. During the early Cold War days, military r&d was the central activity in science and technology in a number of countries, including the United States, France, UK and above all, the Soviet Union. Military r&d dominated because of the relative size of funding, but even more so because of the strong drive towards advancement of military knowledge and technology applications. While the achievement of military performance goals clearly dominated miltary r&d efforts, civilian applications of know-how gained in the military field were

sought, by governments and, at least in Western countries, even more, companies. More often, however, spin-off occured sponateously, when civilian producers adapted knowledge or technologies originally coming from the military sector. Examples abund, particularly in aerospace, space and material sciences, but the overall record of producing civilian spin-off is mixed (Albrecht, 1988; Alic et. al., 1992, Hughes 1994). Technology transfer rates may have been higher in the Soviet Union than in the West simply as a result of central planning. Historic studies indicate that defense research was particularly important for risky technological developments; in the past, when a major military breakthrough was anticipated, defense departments were willing to spend money on unproven technologies. A good example is the transistor and its successor, the integrated circuit (Misa, 1980; Flamm, 1987). Econometric work for single countries, particularly the United States, as well as comparing Western industrialized countries, indicates that military r&d (mostly measured as government r&d) has lower economic advantages than civilian r&d (mostly measured as non-government r&d) (Alic et. al., 1992, pp. 125-131; Glismann et. al., 1993, pp. 132-139, Lichtenberg, 1988). This should come as no surprise, as civilian r&d is specifically geared towards economic gain while military r&d is not. Spin-off decreased in importance with the described shifts in funding. In the Soviet Union, where no such shift occurred, spin-off remained dominant to the end.

Figure 8: Elements of civilian/military interaction

Level	Civilian Sector	Interaction/transfer	Military Sector
Knowledge and technology production	Civilian r&d	← Spin-off → Spin-in → ← dual-use	Military r&d
Production of high-tech goods	Civilian high-tech sector	→ COTS	Military sector
Know-how of research and production of high technology	Civilian r&d sector	← Spin-off → Spin-in → ← dual-use	Military r&d sector
Production factors	Researchers, infrastructur in civilian r&d	← Conversion → Reversion	Researchers, infrastructur in mlitary r&d
Financing of r&d	Civilian funding	← risk technology development ← → Intra-company investments → Funding of strategic sectors	Military funding

- ‘*Warfare and welfare.*’ In some countries, beginning in the 1960s, governments have pursued a dual course of promoting military and civilian technology simultaneously, including their mutual interaction. While sectors remain institutionally separate, cooperation is actively encouraged (OTA, 1994a). This approach was, for instance, adopted in France from the mid-1960s. Military r&d received priority but was implemented in a manner to support strategic civilian industries. Thus, the high cost of developing an independent nuclear weapons force was matched with the development of a large nuclear power sector (Kolodziej, 1987; Hébert, 1995). This strategy is closely linked to industrial planning, which French governments continue to pursue. The role of military r&d has however diminished, and been partly substituted by the strategic use of civilian r&d, for instance in aerospace (Airbus). In other countries, which similarly try to combine industrial development with independent military strength, it remains important.
- ‘*Dual-use*.’ While in the French strategy the focus was on supporting industries with prospects in both civilian and miltary markets, and using civilian and military r&d for this purpose, dual-use strategies aim at developing generic knowledge and technology. The general idea is to have military and civilian r&d contribute to a technology ‘pool’ from which both civilian and military users of technology can draw. The centerpiece of this strategy is government support for high technology that has favorable prospects in both the civilian and military sectors (Gummett and Reppy, 1988; OTA, 1993; OTA, 1994). Dual-use was the pronounced strategy of the Clinton administration of the first half of the 1990s (Stowsky, 1999). Already during the late 1990s, the US began to move away from a dual-use strategy largely because of pressures both from the US Congress and the defense industry, which saw its interests threatened. The strategy adopted since than is similar to that of ‘civil-military integration’ discussed below.
- ‘*Civil-military integration*.’ Military and civilian research have been closely integrated in some countries, with the civilian r&d sector generally in the lead, but with the military r&d sector providing important input, particularly in the development of high-risk industries. Military technology is largely developed through military r&d, however, there is also considerable spin-on of civlian technology. In Germany, for instance, since the mid-1950s, most military r&d occured in large private companies that were also important performers of civilian r&d, such as Siemens and Daimler-Benz. For both civilian and military products, technological capabilities

gained under military r&d contracts were combined with technologies developed for civilian purposes as far as secrecy requirements allowed. Researchers, research infrastructures and assets were used both for the production of civilian and military technology. Thus, there was constant conversion and reversion of factors of production of knowledge and technology. Sweden has had a similar policy of civil-military integration since the 1950s. South Africa adopted a similar strategy after the imposition of an arms embargo in the early 1960s. The US also is operating a variant of this strategy since the late 1990s. Much of new knowledge technology is coming from civilian r&d and industry which is enticed to pursue certain lines of technology by prospects of additional military funding. Military r&d focuses on closing technology gaps on the one hand and on the integration of civilian and military technology for military purposes, in weapon systems but increasingly in networks of systems. System integration is largely done by traditional military companies rather than by civilian companies, which was the preferred option by the Pentagon in the early-2000s. The persisitance of traditional defence companies seems to be the result of political lobbying and barriers to market entry rather than technological capabilities.

- 'Spin in'. The role of miltary r&d in Germany has declined further after the end of the Cold War. Military r&d is reduced to the role of covering areas where no civilian knowledge or technology is available. Most of the technology used in the military field either comes from the civilian sector or is imported. Germany thus has joined a good number of smaller defence producers in Europe and elsewhere where military r&d has a minor role. The Japanese case is also similar. Civilian r&d is clearly predominant. A decision was made in the 1950s to concentrate scientific and technical resources in the civilian field. Domestic weapons are built combining imported know-how and know-how gained in civilian production. Military r&d is subordinate to civilian r&d. In addition to saving resources, this strategy assumes that ultimately economic strength is the basis of military strength (Samuels, 1994; OTA, 1994b).

5. Conclusions

With its latest twist in r&d strategy, the US is going against the direction of trends in the relation between military and civilian r&d. Civilian r&d has increasingly become dominant during the last 50 years in most fields of technology development. Military r&d has become more specialized and focused on covering gaps left by civilian r&d as well as integrating civilian and military r&d in particular projects. Given these trends, it seems doubtful that the larger role given to military r&d in the current US r&d budget is beneficial for US industry in civilian market. It is also not clear that it is yielding concomitant returns in new military technology. Suggestions to follow the US in the direction of higher shares of military to civilian r&d (STAR21, 2002) are therefore questionable (Hagelin, 2004). Indications are that also in the foreseeable future, civlian and military technology generation will increasingly come together, with civilian r&d leading in most sectors.

6. References

Albrecht, Ulrich. 1988. "Spin-off: a fundamentalist approach." In: Gummett and Reppy, 1988, pp. 38–57.

Alic, John A., Lewis M. Branscomb, Harvey Brook, Ashton B. Carter and Gerald L. Epstein. 1992. *Beyond Spin-off. Military and Commercial Technologies in a Changing World.* Boston, Massachusetts: Harvard Business School Press.

Cowan, Robin and Dominique Foray. 1995. "Quandaries in the Economics of Dual Technologies and Spill -Overs from Military to Civilian Research and Development. " *Research Policy*, Vol. 6, No. 6, S. 851 ff

Dombrowski, P., E. Gholz and A. Ross. 2002. "Selling Military Transformation: the Defense Industry and Innovation", *Orbis*, Summer 2002: pp.523-36

Gansler, Jacques. 1996.*Defense Conversion. Transforming the Arsenal of Democracy*. Cambridge, Mass.

Gerybadze, Alexander. 1988. *Raumfahrt und Verteidigung als Industriepolitik?* Frankfurt.

Glismann, Hans H., Ernst J. Horn und Klaus Scharder. 1993. *Wohlfahrtseffekte von Rüstungs- und Raumfahrtausgaben*. Stuttgart.

Gummett, Philip, Mikhail Boutoussov, Janos Farkas und Arie Rip. 1996. *Military r&d after the Cold War: Conversion and Technology Transfer in Eastern and Western Europe*. Amsterdam.

Gummett, Philipp and Judith Reppy, eds. 1988. *The Relations between Defence and Civil Technologies*. Dordrecht: Kluwer.

Gummett, Philipp und Judith Reppy, Hrsg. 1988. *The Relations Between Defence and Civil Technologies*. Dordrecht.

Hagelin, Björn. 2004. 'Science- and Technology-Based Military Innovation: the United States and Europe', SIPRI Yearbook 2004, Oxford, OUP: 285-304

Hébert, Jean-Paul. 1995. *Production d´armement: mutation du systeme français*. Paris: La Documentation Française.

Hébert, Jean-Paul. 1995. Production d'Armement. Mutation du Systéme Francais. Paris.

James, Andrew, Hugh Cameron und Philip Gummett. 1998. Transfer and civil use of defence-related technologies and diversification of defence related SMEs. Program on Policy Research in Engineering, Science and Technlogy, University of Manchester, July 1998.

Koizui, Kei. 2006. R&D in the FY 2007 Department of Defense Budget. American Association for the Advancement of Science, Research and Development FY 2007, http://www.aaas.org/spp/rd/07pch6.htm

Kolodziej, Edward. 1987. *Warfare and Welfare*. Princeton: Princeton University Press.
Kulve, Heiko.te and Wim A. Smit W.A.(2003). Civilian-Miliary Cooperation Strategies in Developing New Technology, Research Policy, Volume 32, Number 6, June 2003, pp. 955-970(16)
Larédo, P and P Mustar (Eds.), (2001), *Research and Innovation Policies in the New Global Economy: An International Comparative Analysis*, Cheltenham, Edward Elgar
Lichtenberg, Frank R. 1988. "Assessing the impact of federal industrial r&d expenditure on private r&d activity in the United States." In Gummett and Reppy, 1988, pp. 68–87.
Markusen, Ann und Sean Costigan. Eds. 1998. *Arming the 21st Century*. New York.
Misa, Thomas J. 1980. "Military Needs, Commercial Realities and the Development of the Transistor, 1948-58." In Smith, 1980, pp. 253–287.
National Science Board. 1994. *Science & Engineering Indicators 1993*. Washington, DC: Government Printing Office.
Nelson R (Ed.), (1993) *National Innovation Systems: A Comparative Analysis*, Oxford, OUP
Noble, David. 1977. *America by Design. Science, Technology, and the Rise of Corporate Capitalism*. New York.
Organisation for Economic Co-operation and Development. 2003. *Main Science and Technology Indicators.* Vol. 1, Paris.
Reppy, Judith. 1998. "The Future of Defense r&d." In Markusen and Costigan, 1998.
Samuels, Richard. 1994. *'Rich Nation, Strong Army': National Security and the Technological Transformation of Japan*. Ithaca, New York.
Smith, Merrit Roe. 1980. *Military Enterprise and Technological Change*. Cambridge, Mass.: MIT Press.
STAR 21 European Advisory Group on Aerospace. 2002. *Strategic Aerospace Review for the 21st Century*. Brussels: European Commission.
Stowsky, Jay. 1998. "Dual-Use Policy as Industrial Policy." In Ann Markusen and Sean Costigan. *Arming the 21st Century*. New York.
Theile, Burkhard (2005), *The Defence Technology Industry in a Time of Force Transformation and Internationalization*, Available at: http:/// (accessed 4 July 2006)
United States Congress. Office of Technology Assessment (OTA). 1993. *Defense Conversion: Redirecting r&d.* OTA-ITE-552. Washington, DC: Government Printing Office.
United States Congress. Office of Technology Assessment (OTA). 1994. *Assessing the Potential for Civil-Military Integration.* OTA-ISS-611. Washington, DC: Government Printing Office.