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A resource-based model using System Dynamics to investigate how to improve the performance of a value chain that produces advanced weapons

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8) ABSTRACT

This document describes a System Dynamics model of a value chain that produces advanced weapons. The model merges two distinct traditions of strategic analysis; System Dynamics and the Resource Based View. A simulation model is developed and used to exemplify the approach. In the model, four resource aging chains interact; military men, industrial workers, R&D professionals and defence equipment. The model is initialised to portray both the US and European defence technology status in 2003. 25 year simulation runs are provided for US and EU base cases, as well as to investigate four European policy options: Budget policy, Industrial policy, Conscription policy and a Combined policy. It is found that a Combined policy succeeds in cutting in half an initial eight-fold US lead in advanced fieldable military equipment.

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A RECOURCE-BASED MODEL USING SYSTEM DYNAMICS TO INVESTIGATE HOW TO IMPROVE THE PERFORMANCE OF A VALUE CHAIN THAT PRODUCES ADVANCED WEAPONS

1 BACKGROUND

During the last decade European nations have said that they want to close the technology gap between them and the US (NATO, 2004; Heier, 2004). NATO documents have typically pointed out the need to increase defence budgets, synergize defence industries and intensify R&D efforts (Gholz and Saplosky, 1999; Küchle, 2001). However, the technlogy gap continues to widen (Bakken, 2004). There may be many reasons for this apparent paradox. People often say one thing that is opportune at the moment, but make diametrically opposed decisions (Argyris and Schõn, 1978). Related to this "lip service" argument is the high economic and political costs of higher defence budgets and other proposed solutions.

2 METHOD

Two modelling paradigms are merged and used in this paper: The mostly quantitative System Dynamics (Forrester, 1961; Sterman 2000) and the mostly qualitative Resource Based View in [corporate] Strategy (Hamel and Pralad, 1984).

System Dynamics (SD) (Forrester, 1961; Sterman 2000) evolved from servomechanism (engineering) theory and praxis to tackle complex organizational and market dynamics (Forrester, 1961) as well as societal questions such as urban and world dynamics (Forrester, 1969; 1971; Meadows et al, 1971). Modelling often follows a three-step sequence;

1. Develop a "reference mode" i.e. a succinct, quantitative, depiction of a "problematic" behaviour that shows key variables as a function of time.
2. Find a plausible candidate of stock- and flow and information feedback system that could have produced the "reference mode." There exist checklists for developing such a system (See e.g. Richmond, 1985)
3. Retain a system that reproduces the behaviour mode using historical parameter values. The reproduction of the "reference mode" is a key to validation. (Forrester, 1971; Barlas, 1989)

The model hence validated, one proceeds to define, select and test possible policies that might improve upon system behaviour. A key focus is design/choice of comparably good outcomes, through a reasonable combination of parameter values using the validated model. If good outcomes cannot be achieved in such a way, a revised stock- and flow structure, alternatively the redesign of information feedback mechanisms, may be required (Merten, 1988). Validation must then also be reassessed.

The Resource-Based View (RBV) (Hamel and Pralad, 1984) evolved in an effort to understand questions of corporate strategy. Such questions typically address how corporate management can position a firm's products in a landscape of customers and competition. A key issue hence becomes to understand developments in the external world (Porter, 1980). RBV proponents focus on dynamics within the firm: How should inside resources (men, competencies and machines alike) be defined, designed and developed as cornerstones for successful corporate strategic development so as to achieved the desired positioning (Løwendahl, 2005).

RBV would probably view advanced defence technology as the outcome over time of an interacting web of physical and human capital. The focus of interest would be policies for how these resources should be transformed from the present state of affairs into their needed end-state in order to produce an actor's (e.g. EU) desired technology.

There is no opposition between SD and RBV (Morecroft, 1998; Warren, 2002). SD can on the contrary be seen as a vehicle to make resources tangible and induce tacit information feedback mechanisms out in the open. In addition, the stock- and flow nature of the SD model also forces the RBV to be concrete, and if one desires, flesh out qualitative assumptions in numerical form. An SD approach to the technology gap would also require explicit stocks of people, industrial facilities, labs, defence equipment etc. of various categories. They would be linked with information and physical feedback, thus creating self-reinforcing and balancing loops (Sterman, 2000). Thus, policy changes would have to be defined as a stream of decisions that would impact resource flows and consequently influence resource stocks.

3 REFERENCE MODE

There is no discussion of the existence of a US defence technology supremacy, and that EU[1] should attempt to become more even (NATO, 2002; EU, 2003). But few venture into estimates of even an approximate estimate of the current size of the gap. Reasonable assumptions, used below, however, estimate that the EU[2] battle relevant inventory only is 10 to 20 % of the US'. This estimate assumes that US and UK used a similar proportion of their total forces in the 2003 Iraqi war and that the total use of weapons are reflected in Wahl et al. (2004) as shown in table 1 below. The estimate furthermore assumes that France could have replaced UK in that war with a similar force, or that the rest of Europe could have, also. Thus, the 1/23 (768/18101) capability fraction of UK/US indicated in table 1 translates into a 3/23 fraction for the EU as a whole. The US stock of battle relevant equipment thus is almost eight times that of the EU.

[1] In this paper, "EU", "NATO Europe" and "Europe" are used interchangeably.

	US	UK
Tomahawk	802	?
CALCM CM	153	0
Storm Shadow CM	0	27
Laserguided bombs	8618	263
Laser and GPS bombs	98	392
JDAM (GPS bombs)	6542	0
Maverick missles	918	39
Hellfire missiles	562	0
Radar homing missiles	408	47
Advanced weapons, total	18101	768

Table 1: Advanced military hardware on both sides of the Atlantic, used in the Iraqi war (Wahl 2004). Note that for Tomahawk cruise missiles, the UK figure is classified. The total here assumes 0, but UK Tomahawks were highly probable in use. The conclusions are however robust to the uncertainty in UK Tomahawk numbers.

The 780 % US "advantage" is a cumulative result of five major differences between the US and EU. First, the US has had higher defence budgets, by about 50 %. Second, US use a higher fraction of their budgets – about 50 % - on investment. Thirdly, the US additions to investments used for R&D is also more than 50 % higher than in the EU. Fourth, soldier numbers in the US are only about half of what they are in the EU. Last, but not least, the US defence industry is much more concentrated in terms of number of industrial corporations than in the EU. Figures 1 to 4 below show the consistency in these differences between EU and US over the 24 years from 1980 to 2003.

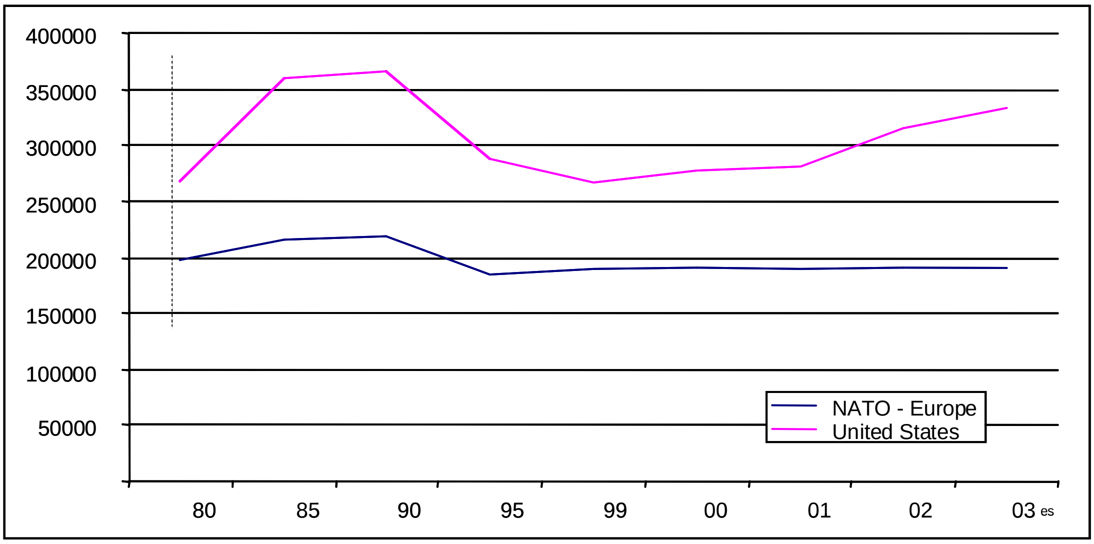


Figure 1: Defence expenditures, for NATO Europe and the US. 1995 USD million (NATO, 2002a).

Figure 1 however also shows slightly more volatility in the US data. Nevertheless, US budgets never exceed 160 % of EU's and never fall to less than 140 %. Similarly, the US/EU relative investment ratios only vary between 1.4 and 1.6 as shown below.

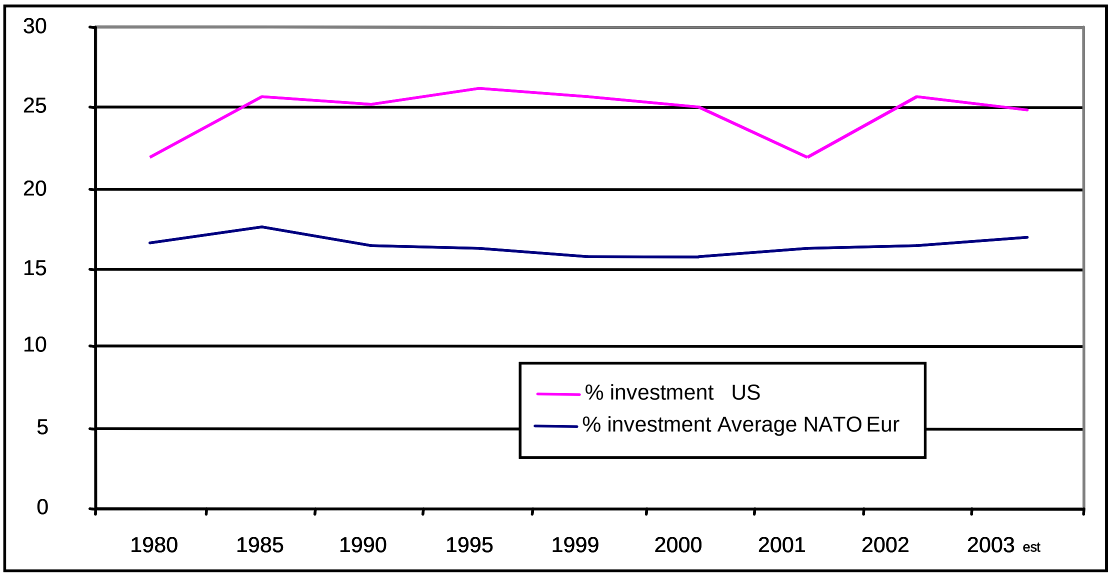
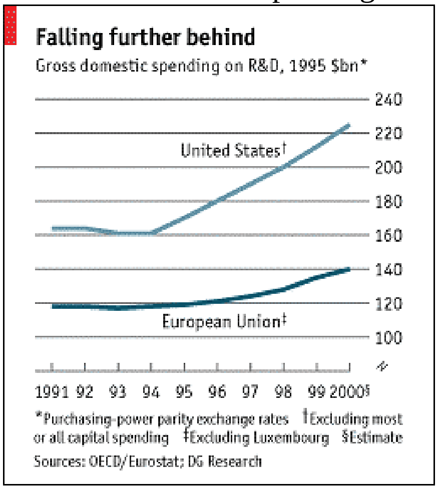


Figure 2: Percentage of US and EU defence budgets used for equipment purchase (NATO, 2002a)

In absence of comparable time series data of EU and US defence R&D data, civilian time series has been used in figure 3. A table of 1999 US and EU defence R&D data is also shown. Given the consistency of the time series shown in figures 1 to 3, it can be extrapolated from figure 4 that a hypothetical *defence* R&D time series would have shown a 50 % higher proportion of US defence investment spending devoted to R&D.



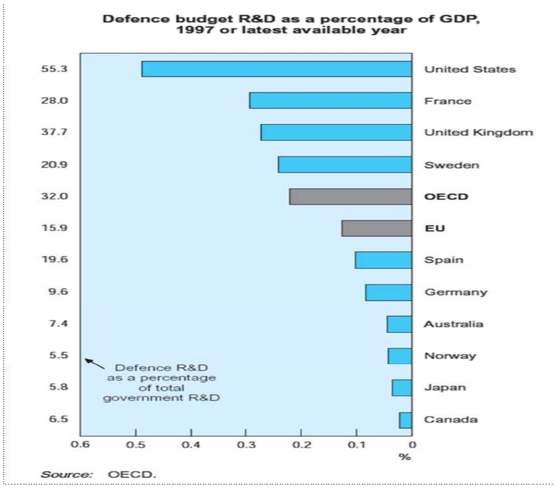


Figure 3[3]: R&D as % of GDP, (OECD, 1999)

Figure 4: R&D, historical, for EU and the for selected states

[3] Figure 4 moreover shows the three divisions in military capabilities. First there is the US, spending over 0.5 % of GDP on defence R&D. This amounts to over half of its government R&D. In the second league are the two other nuclear weapon states France and the UK. They also share long stories of expeditionary warfare and capabilities and they spend more of government R&D on defence than on any other category. The third league is the rest of NATO Europe which spends very little.

Similarly, the EU has consistently employed about twice as many men in active duty as has the US as shown in figure 5 below.

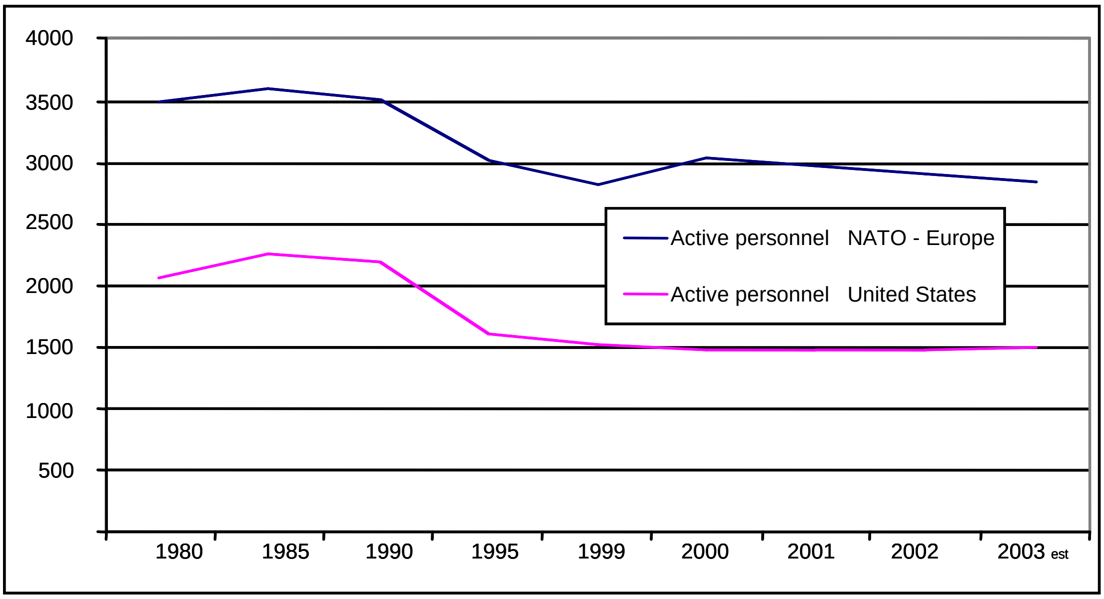


Figure 5: US and EU active men in uniform.

The fifth major difference between the US and EU relevant to the technology gap is the higher US defence industrial concentration. Especially in the 1990 to 1995 period, the US industrial structure saw a reduction in both and numbers of plants *and* corporations. Though there still exist a great potential for further improvements in effectiveness in the US industry (Gholz and Sapolsky, 1999), the EU defence industry appears less transformed (Küchle, 2001).

The persistency of EU and US differences is remarkable in a period when official policy statements have called for their disappearance. As will be noted later, the persistency is indicative of strong organizational and societal anchoring processes. These tend to counter desired policies stated both at the NATO headquarters in Brussels and in the respective European capitals. A model that attempts to address the failures to close the defence technology gap must make such anchoring processes explicit.

4 VALUE CONFIGURATIONS AND VALUE CHAINS

There is a truism that some transformation process must exist to accumulate defence dollars and turn it into defence capability. A common way to conceptualise this industrial transformation process is to call it a value chain – to indicate that customer satisfaction or any other ultimate value is found at the end of a multistage input-output process. More generally, however, Stabell and Fjeldstad (2000) have argued that value configurations should be conceptualised into three categories: Value Chains, Value Networks and Value Shops. Whereas industrial transformation organizations typically are of the first type, telecom firms and finance organizations typically the second, consulting and engineering firms are typically value shops. Though there are elements of all three value configurations in the defence industrial transformation complex, the primary conceptualisation category is here chosen to be a value chain because of the core importance of industrial transformation. Figure 6 shows this value chain.

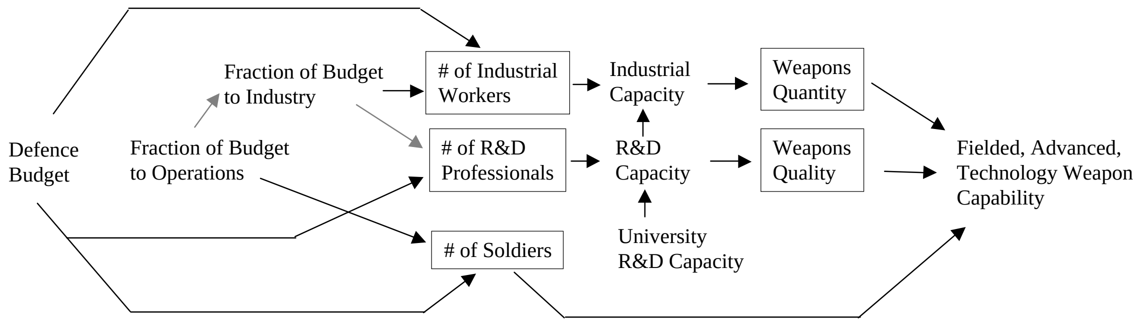


Figure 6: The ADTG value chain wherein the defence budget is turned into arms via three professions (industrial workers, R&D professionals and soldiers).

The value chain is assumed to be identical in the US and in the EU. Moreover, EU is here considered as a whole – as a single market. In addition, there is an implicit assumption that EU or US industrial processes can be regarded devoid of corporate substructures.

Figure 6 follows the monetary flows and conversion of money into physical resources: The defence budget is divided into three payments to allow the upkeep and hiring of three personnel stocks: industrial workers, R&D professionals and soldiers. The money flow is assumed to follow a waterfall process. First the planned fraction of the budget for current operations is allocated. What is left goes to industry, primarily to weapons systems purchases. Within the defence industry, the plants have priority over the (fewer, but better paid) R&D workers. The industrial capacity is hence determined by the size and experience level of the work force, modified by the size of the R&D work force that devotes itself to industrial process improvements. The R&D capacity is itself determined by the size and experience level of the R&D work force, modified by the strength of the ambient R&D community. The university R&D system is used as a proxy for the ambient R&D system. Weapons quantity follows the industrial capacity and their quality follows the R&D capacity. Military capability is the final output and a direct function of the number and experience level of the soldiers as well as of weapons quantity and quality.

5 CAUSAL LOOP DIAGRAM

A causal loop diagram (CLD) purports to show plausible causal mechanisms behind the issue at hand (in this case, the technology gap's persistence over time) taking into account overt and notably less obvious information feedback (Forrester, 1961; Sterman, 2000).

As shown in figure 7, the CLD expands the value chain so as to include feedback mechanisms. While the transformational nature of arms productions remains in focus, there is added emphasis on the importance of decision making processes. In particular, the various professions (soldiers, R&D workers, industrial labour) are omitted and replaced by their effects (Industrial, R&D and Military Capacities)

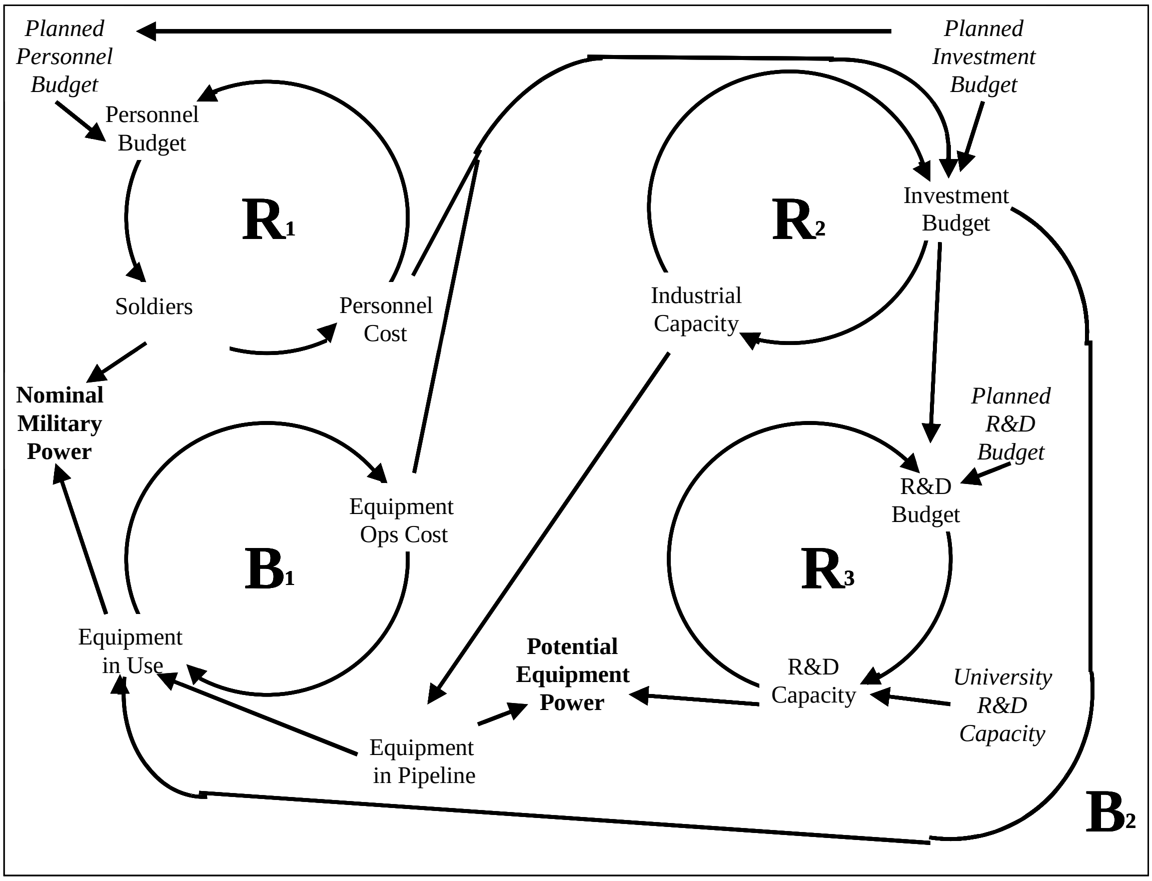


Figure 7: *CLD explaining the time trajectory of military power.*[4] *The same diagram individually explains the EU and the US.*

The CLD has three self-reinforcing processes (R1, R2 and R3). These all state an anchoring part of and "anchoring and adjustment" – heuristic (Sterman, 2000) and indicate the following; the higher the capacity and the larger the work force, i.e. the higher the funding of military men, the industrial capacity and R&D capacity, the more inertia builds up in the area. Stated differently, these loops explain the momentum of current policies. If one e.g. starts off with a large military work force, this momentum acts so as to drive personnel costs and later personnel budgets higher than they otherwise would have been.

The CLD assumes the same planning hierarchy as was explained for the value chain where personnel budgets are planned first, then investment spending and third R&D outlays. This corresponds to a recent survey long-term defence planning methods in NATO (Bakken, 2002). The CLD assumes that total annual Defence budget is exogenous. This implies that the sum of the sub-budgets for military manning, equipment operations; purchase and R&D must somehow be balanced within each single year (B1). Balancing is assumed to materialize in two ways. First, as operations cost increases, equipment is retired (Tisdahl, 2004) mostly through less intensive service and mothballing, but also through less aggressive deliveries or delayed introduction of previously ordered equipment. Secondly, higher operations costs reduce the actual investment budget levels from those planned (B2)[5].

[4] The three self-reinforcing loops (R1, R2 and R3) all assume that "Capacity" is derived from the total work force and their average experience in the respective sectors, but are not shown here to maintain clarity. Several balancing feedback mechanisms in the budgeting process are similarly omitted in this diagram.

[5] There is however no explicit treatment of the investment cost overrun dynamic.

6 LOGIC AND STRUCTURE OF THE SIMULATION MODEL

The model captures the CLD. There are however several issues that are expanded, notably a quasi-zero-sum structure with respect to funding implemented as a hierarchy where soldier salaries have priority over equipment operations costs, that again have priority over the defence industry with flexible ordering deciding what is eventually ordered and delivered. R&D personnel are last.

The above-mentioned labour stocks – and related capabilities have been transformed from a CLD to a stock- and flow structure. Moreover, an equipment production, use and retirement-chain has been made explicit. In this equipment chain, the pipeline eventually (i.e. with an average delay of five years after a decision to start production has been initiated) becomes operational (i.e. *in-use*) and is taken out of service after an average time of fifteen years.

Recall that the purpose of the model is to enable an investigation of how Europe's defence industry might catch up with the US in terms of total defence capabilities. A key issue then is what it will take to develop the constituent parts of the EU defence-industrial conglomerate. Two sub-issues stand out: What does it take and how long will it take? Developing key defence capabilities consists in the developing the right quantities mixed in the right way. If one takes an endogenous view, as is done here – i.e. no equipment can be acquired from outside the system, then all capabilities are the outcomes of a well balance mix of people and equipment. But equipment is itself the result of prior involvement of people, notably industrial workers and R&D professionals. Closing the capabilities gap is a lengthy process. In a long time frame all resource policy questions, also those relating to achieving technological parity, might be regarded as a question of how to allocate scarce money to different types of people.

Consequently, the model consists of three aging chains of people, common to all three is that *young* ones "graduate" to *experienced* after five years and then retire after another twenty-five years;

- Soldiers (includes all military personnel, civilian and uniformed of all ranks)
- Industrial workers (includes all manufacturing personnel of all ranks)
- R&D professionals includes all R&D personnel of all ranks

The stock-and flow diagram is shown in figure 8 below.

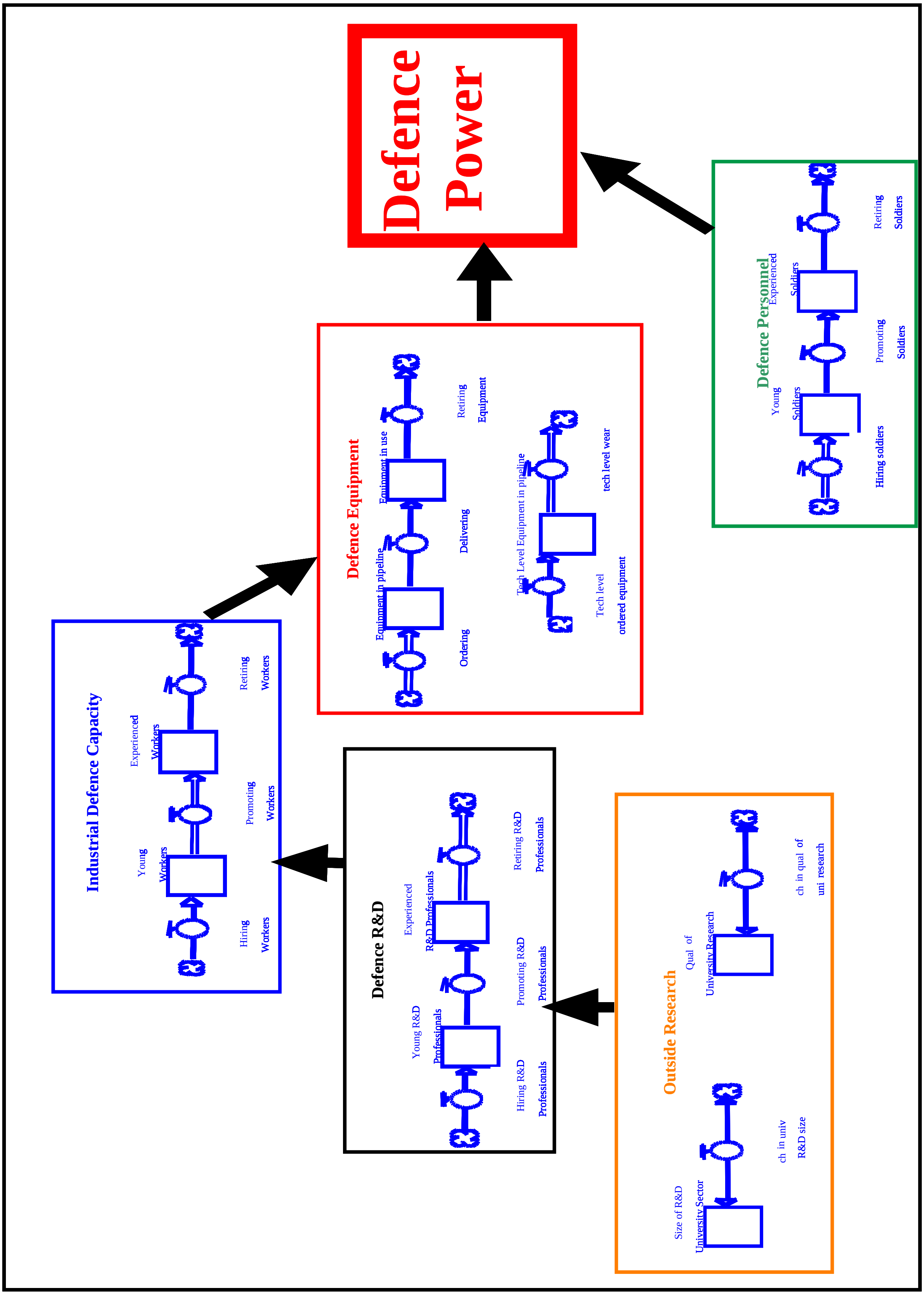


Figure 8: Stock- and flow structure of the model.

The model's equations are shown in the appendix. Initialisations however were done with a mixture of empirical and synthetical data as shown in table 2 below.

	2003 GDP	1997 USD to R&D	1997 % to mil R&D	Mil manpower 2003	Soldier pay totals	R&D manpower	R&D pay totals	Investment budget	2003 % to investment	2003 defence budget	Industrial workers
US	10000,00	50,00	0,0050	1500,00	60,00	300,00	30,00	83,00	0,25	332,00	1494,00
"NATO" Eur	9500,00	14,25	0,0015	3000,00	60,00	171,00	8,55	31,68	0,16	198,00	1140,48
EU/US	0,95	0,29	0,3000	2,00	1,00	0,57	0,29	0,38	0,64	0,60	0,76

soldier individual pay US 50 000 USD
soldier individual pay EU 25 000 USD

worker individual pay US 50 000 USD
worker individual pay EU 25 000 USD

R&D individual pay US 100 000 USD
R&D individual pay EU 50 000 USD

Budget fraction to R&D US: 0,15 *Budget fraction to Investment & R&D US: 0,40*
Budget fraction to R&D EU: 0,07 *Budget fraction to Investment & R&D EU: 0,23*

All numbers are fractions or billion USD/year unless marked otherwise

Table 2: Computation of initial parameter values.

In particular, total stocks of initial personnel were determined by dividing 2003 budgets by assumed average salaries. Similarly, it was assumed that 2003 force structures were in balance, thus was determined by the mix of experienced and inexperienced industrial workers, R&D professionals and soldiers. Last, the equipment stock was measured in billion dollar values. Here, too, assumptions of life time and delivery delays defined the total equipment stock and its partitioning between "equipment in use" and "under delivery".

7 VALIDATION

The model was validated behaviourally.[6] First, historical budgets were fed into the US and EU model versions respectively. This allowed a validation of personnel stocks. Time series data were found only for soldiers. Simulated and historical soldier numbers for US and EU are compared below.

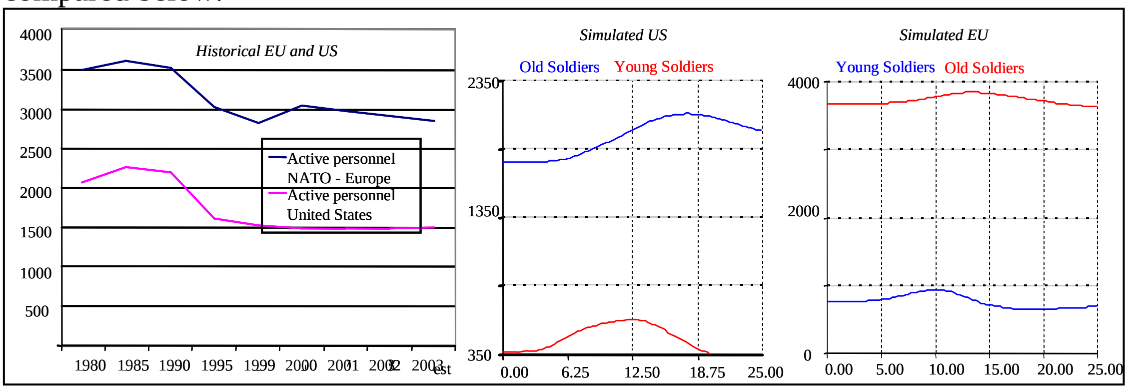


Figure 9: Historical manning *Figure 10: Simulated US Manning* *Figure 11: Simulated EU Manning*

The validation indicates that the model's budget hierarchy of assuring operations cost first leads to a stronger increase when budgets increase than do historical data. Similarly, as budgets decrease, simulated manning falls less than historical. The end result is that simulated soldier manning is higher than historical. Though it has proved impossible to find time series data for industrial and R&D manning – simulated numbers are shown below.

[6] ithink, a System Dynamics simulation tool from isee systems of Lyme, NH, USA was used. ithink 7.0 runs under Windows and Macintosh operating systems. Execution time was less than 1 second using a (1999) Apple Macintosh Powerbook 3G.

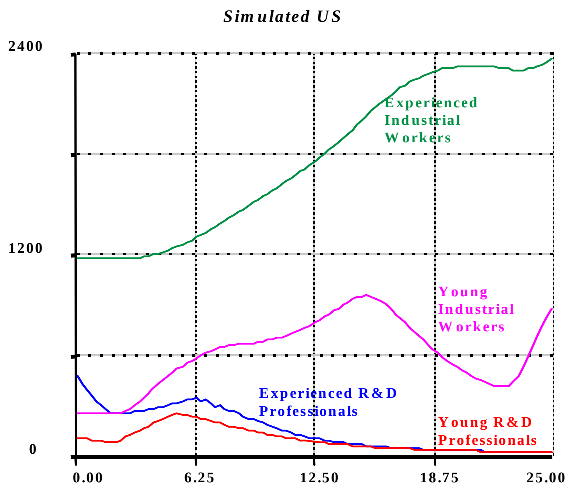


Figure 12: Simulated US industrial and R&D manning.

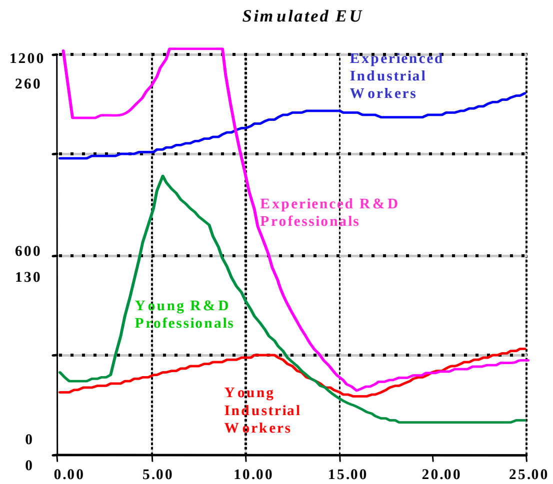


Figure 13: Simulated EU industrial and R&D manning.

Figure 13 shows what happens as the historical budget data are forced into the model. Recall from figure 1 that these budgets grew in the years 1980 to 1990, and retracted 1990-1995 in both the EU and the US. Then they grew again in the US 95-2003, while EU experienced flat budgets the last 8 years. Figures 12 and 13 show that both US and EU industrial worker numbers are increasing over the entire period. Though no historical time series for industrial workers was obtained, both Gholz and Sapolsky (1999) and Küchle (2001) indicate a delayed, yet significant effect of reduced budgets on industrial labour size.

Who has paid for the increasing numbers of simulated soldiers and industrial workers? Figures 8 and 9 shows that R&D workers have been more than halved in both US and the EU. Again, though no statistics were obtained on the dynamics of R&D workers, the real decline in the R&D community must have been less than indicated by the simulation.

It appears that the model works logically in times of budget growth. However, in times of subsequent budget decline, the positive feedback mechanisms ensure that the prioritised soldier and industrial worker categories are able to sustain and even grow their size. Their growth momentum is enabled through the reduction of the R&D worker numbers. The R&D community itself enters in downwards spiral where initial decline is made worse both by the community's low budget hierarchy position and by lack of momentum.

The fact that the model overstates the negative effects on the R&D community in times of reduced budgets, may however have a flip side in that the R&D community benefits more than the industrial and soldier communities in times of initial and sustained budget increase. This was tested and shown below in figures 10 and 11. Here, the overall defence budget increases by 2 % a year. In such a situation, the R&D community becomes a real "budget winner" as the size of the R&D community more than triples, whereas no other personnel group increase more than 30 %.

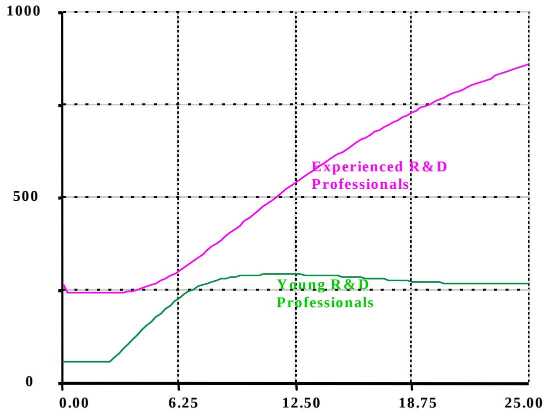


Figure 14: Simulated EU R&D manning

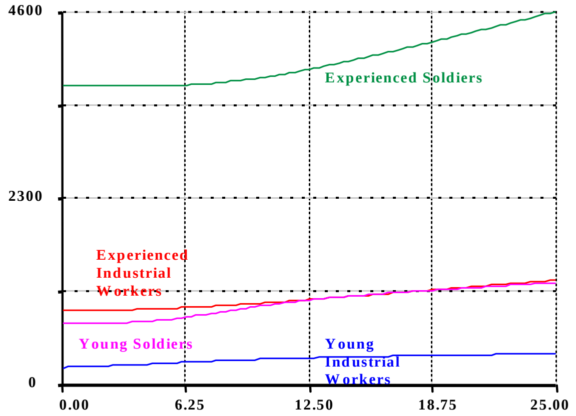


Figure 15: Simulated EU industrial and Military manning.

As no option involving budget decrease will be investigated in later policy tests, but only focus on growing R&D budgets, the model's "weakness" in the budget fall area is not a major one. On the contrary, the perhaps optimistic R&D growth should be noted in policies where budgets are assumed to grow.

8 BASE CASE RUNS

The model was first initialised for the US and run. Secondly, it was initialised with EU parameter values and then run. Initialisation values for base case runs are shown in table 3 below.

Parameter	**US value** Base case	**EU value** Base case	**Comment**
Young soldiers, initial	350 000	735 000	
Experienced soldiers, initial	1 750 000	3 675 000	
Young R&D professionals, initial	90 750	51 728	
Experienced R&D professionals, initial	453 750	258 638	
Young workers, initial	233 333	177 333	
Experienced workers, initial	1 166 667	886 667	
Equipment in pipeline, initial	385 000	192 500	Million dollar asset value
Equipment in use, initial	1 186 000	593 000	Million dollar asset value
Total budget, initial	330 000	202 000	Million dollars
Industrial productivity	f(R&D producivity, economy of scale)	f(R&D producivity, sqrt(economy of scale))	

Table 3. Initial parameter values.

Graph 1 below shows the base case with 25 year stable defence budgets at current 330 $ billion level for the US and 198 $billion level for EU and no policy changes are made:

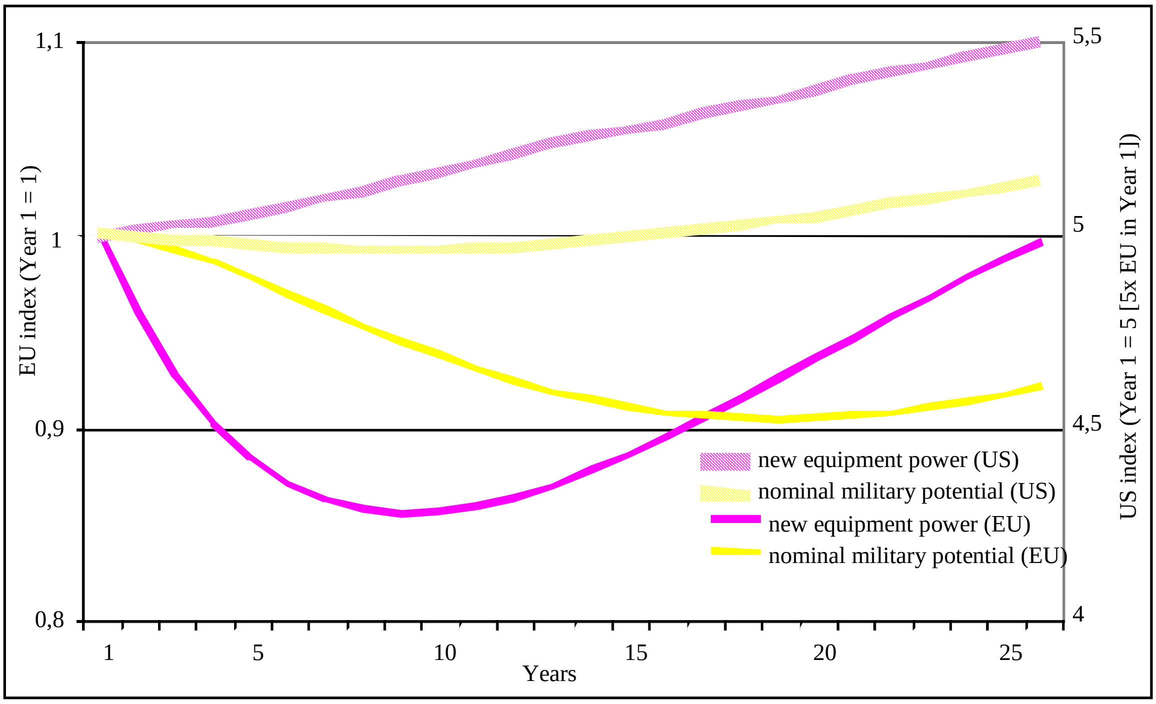


Figure 15: Base case[7].

In figure 15, the technology gap continues to increase; the initial five-fold gap[8] is increasing for the entire 25-year simulation period. Worse than that, the European performance indicators are both falling for the first 10-15 years, not to recover to initial levels before year 25. The EU loss is mostly caused by low EU investment levels, too low to enable a replacement of aging equipment stock.

9 POLICY ANALYSIS

It was decided to investigate three different policies that are often proposed in Europe to close the Atlantic technology gap (Economist 2003 and 2004):

1. Industrial policy: Consolidate European defence industry, and at the same time increase the ambient (non-defence) R&D sector size[9]and level by a factor of three [at no cost to the Defence Sector]. Constant defence budgets.
2. Budget policy: Bring European annual defence spending up to US levels; i.e. by 60 % (in 25 years).
3. Defence policy: Convert Europe's huge, poorly trained partly conscript forces to professional ones better suited for expeditionary operations. Constant defence budgets.

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[7] Two variables were used to indicate various aspects of military technology:
1. *New equipment power:* Applies the current applied technology frontier (TF) to the amount of defence hardware in the ordering pipeline. It thus is an indicator of the quantity and quality of equipment **about to be operational**. This indicator thus also includes how much hardware has been ordered over the preceding five years (which is assumed to be the [exponential] average gestation time for such hardware).
2. *Nominal military potential:* Averages TF over the **whole** life-time of hardware, and applies it to the total amount of military hardware inventory and adjusts for the military manning size.

[8] The US index is set initially to 5, reflecting the earlier Iraq war based estimation of a 7.8 factor US advantage. Both this and other estimates are attempted kept so as to provide a conservative US value, and a positive EU value.

[9] SPRU (1996) shows that R&D impacts economic growth in highly uncertain and complicated ways. The above discussion however clearly indicates the importance of defence R&D for defence output.

The parameter matrix of the three EU policies are shown in table 4 below.

Parameter	**EU value** Industrial policy	**EU value** Budget policy	**EU value** Defence policy
Industrial productivity	f(R&D producivity, economy of scale)	f(R&D producivity, sqrt(economy of scale))	f(R&D producivity, sqrt(economy of scale))
Budget annual growth rate	0 %	2 %	0 %
University R&D growth per year	2,50 %	0 %	0 %
University R&D quality improvement per year	2 %	0 %	0 %

Table 4: Parameter differences; Three EU policies.

9.1 Industrial policy

It is often argued that the triumph of national politics in Europe, that is the lack of a common industrial policy, is the main cause of the gap. In order to investigate this claim, a consolidation of industrial policy was implemented mostly by an immediate and lasting boost to European industrial productivity. At the same time, a related policy coordinated European ambient R&D policy by rewarding quality much as is done by the US National Science Foundation. This would not have to cost anything in financial terms; Europe already spends more government funds on non-military R&D than does the US. On top of that, this industrial policy assumes that the ambient corporate R&D efforts initially jump to US levels. The cost of the entire policy will be borne outside of government.

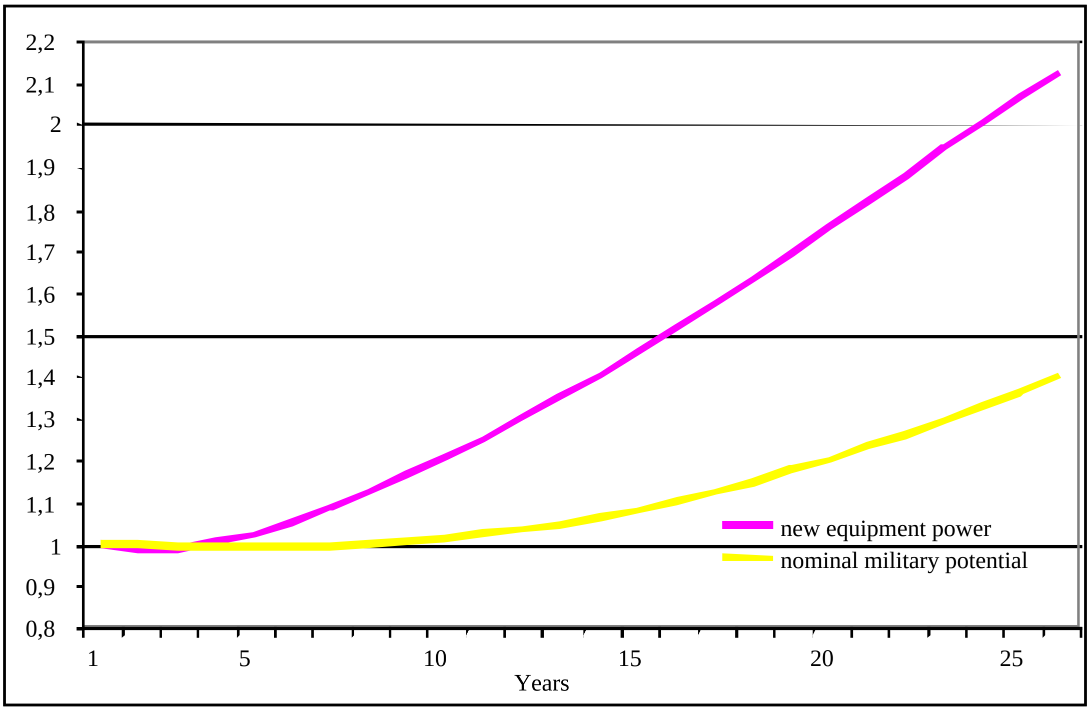

Figure 16: Implementation of a successful industrial policy.

A successfully implemented industrial policy indeed helps to close the technology gap, but very marginally. With all the positive assumed effects – and all for free, the EU power increases to 2.1 from 1, whereas figure 15 showed that the US indicator US increased to 5.5 from 5 within a 25-year time frame.

9.2 Budget policy

Assuming that European defence budgets increase about 2 % per year, they will attain US levels in 25 years[10]. The policy consequences are shown in figure 17.

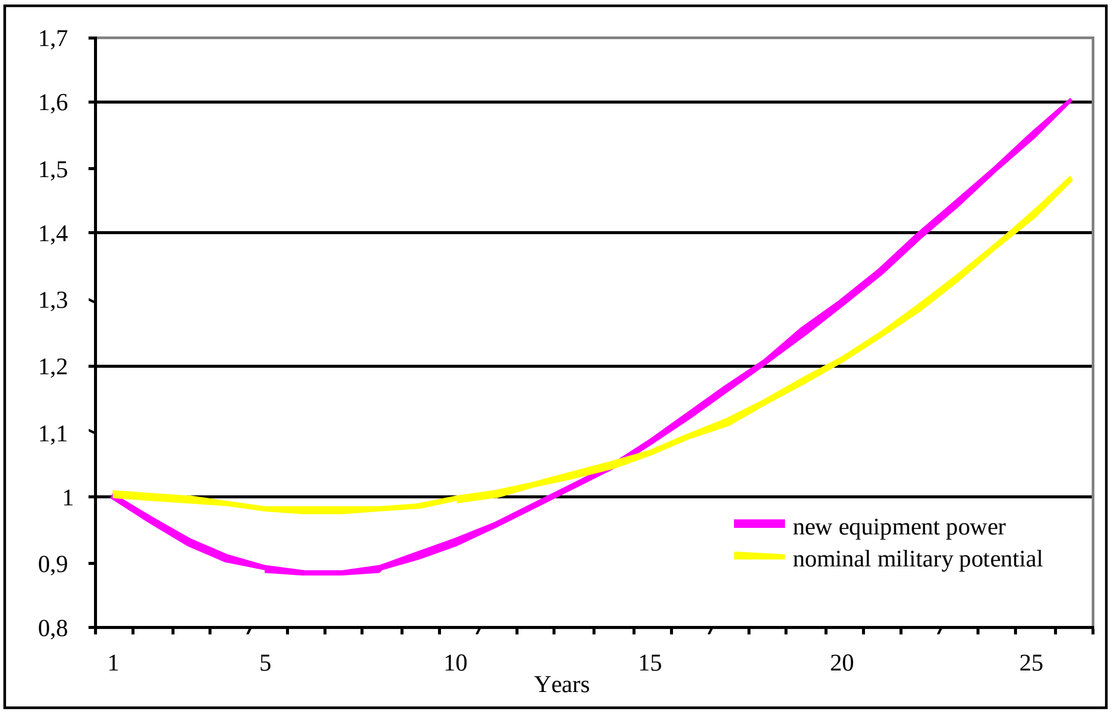

Figure 17: Consequences for EU of achieving US defence budget levels in 25 years.

Compared to the previously investigated industrial policy, a defence budget policy delivers less. However, a budget policy is more powerful in the longer run, and the ”new equipment power” indexes for the two policies cross each other after about 5 more years, after which the budget policy wins (not shown here).

9.3 Defence policy

This policy assumes instant conversion of all conscript forces to professional ones at no cost. The policy is implemented by assuming that professional forces are better trained and perform better, especially with more advanced equipment.

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[10] USD 2003 fiscal year budget was USD 330 billion; EU consolidated 2003 budget was USD 202 billion. 2003 was base case initial year.

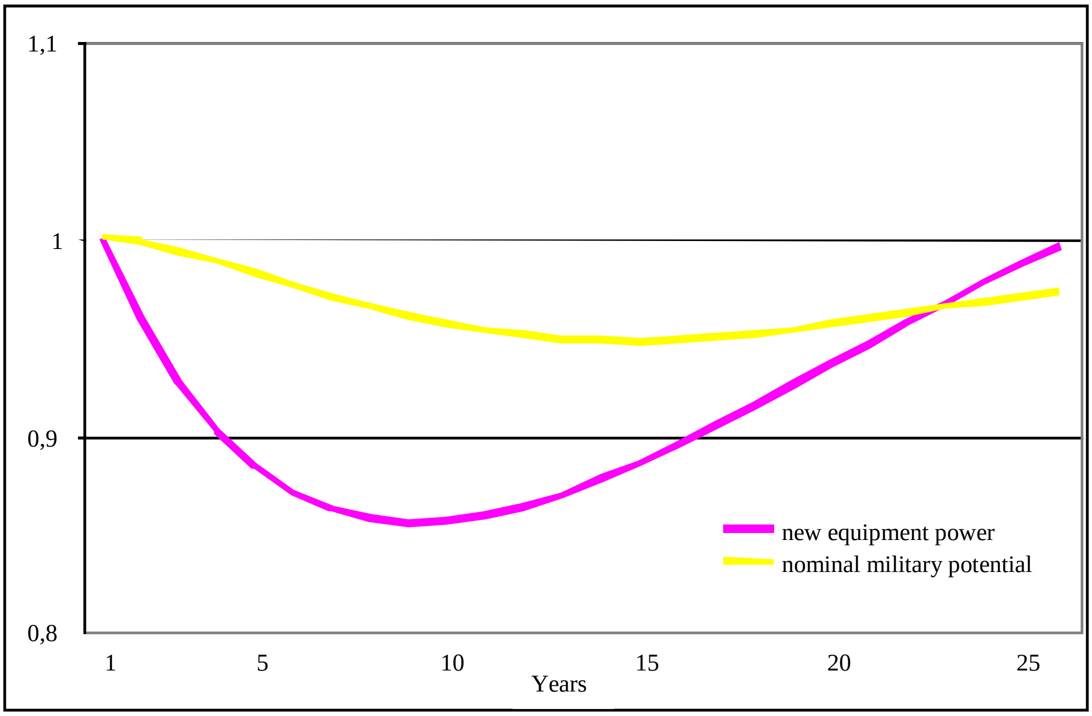

Figure 18: Defence policy; conscription forces are substituted by professional ones.

A transformation of largely conscript forces into professional ones shows very limited results. The main reason is the slow introduction of new high tech arms. It does however help the military potential to fall slower than in the base case.

9.4 A combined policy

All three policies were then combined. The results are shown in graph 5.

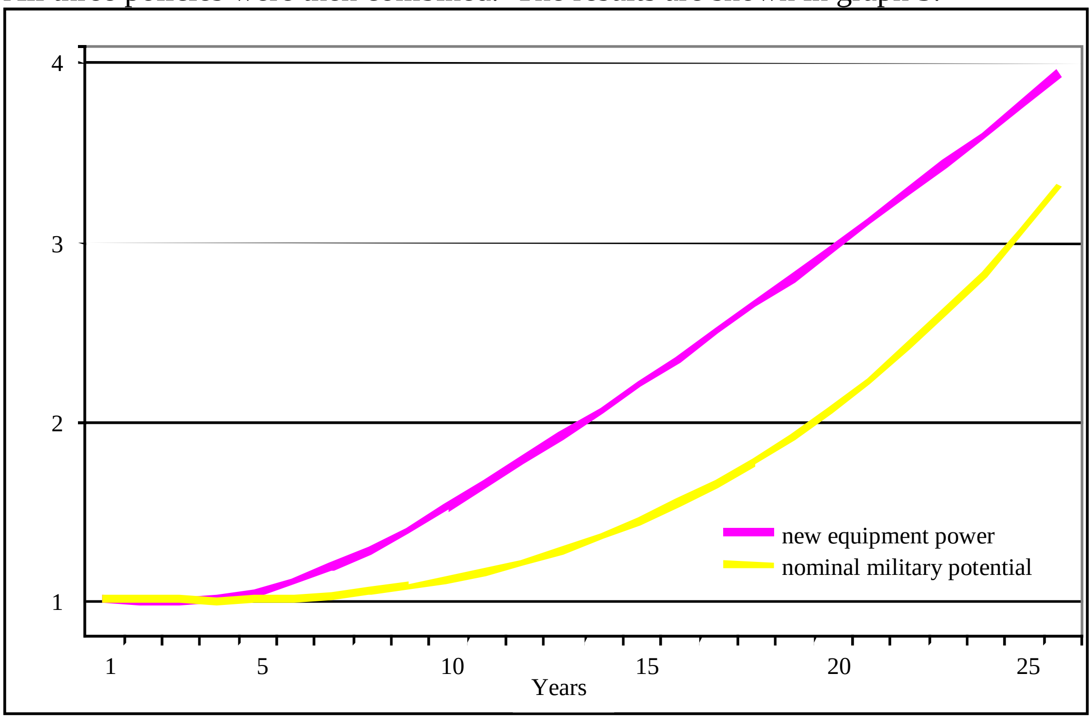

Figure 19: A concerted combination of an industrial, budget and defence policy.

Not surprisingly a combined policy outperforms all others run separately. However, the simulation also shows synergy effects between the policies, they are multiplicative rather than additive. But even this combined policy only marginally closes the initial technology gap. It was noted that the gap today amounts to a factor 5-10 when it comes to advanced fielded hardware, whereas only a factor 4 is achieved in 25 years with a coordinated set of policies.

9.5 Policy analysis summary

The implementation of a defence policy through an expeditionary type soldier force across the board proved to help little. The added cost of voluntary soldiers about offset their higher quality and lower numbers. A budget policy of achieving US levels (USD 330 billion) in 25 years was more successful. But even this policy closes less than 1/6 of the initial five-fold gap. Restructuring the defence industry helps most. Yet, it takes ten years to achieve any results, and after 25 years, the index of new military power shows only a 120 % increase. Finally, running the three policies in parallel yields some limited synergies, yet closes only 3/4 of the gap.

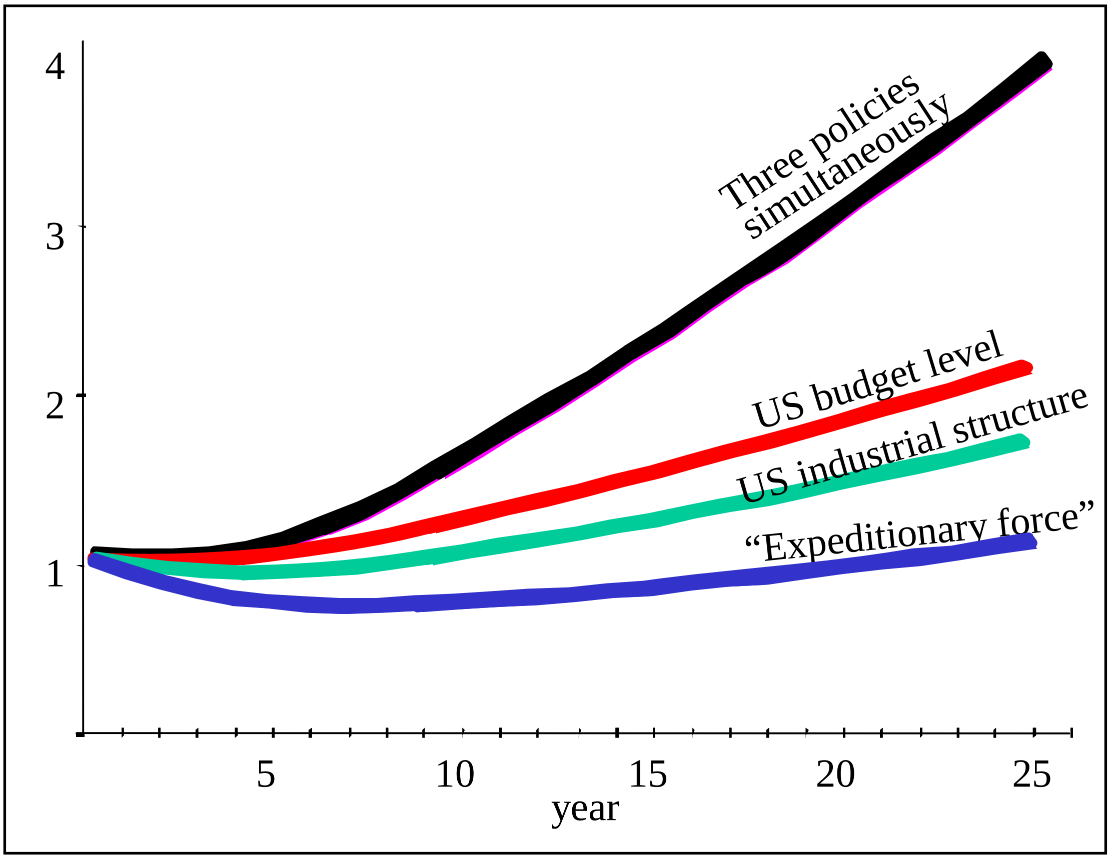

Figure 20: The effects of simulating three policies separately and combined.

10 WEAKNESSES

The model is an attempt to quantify defence policy assumptions and thus achieve numerical results so as to be better able to evaluate the results of these policies. The policies all attempt to close the defence technology gap. The method has tried to merge SD with mainstream corporate strategy research methods, in particular the RBV and the value chain approaches.

The main weakness of the model is its reliance on too strong loop gains in the R&D sector. This leads the R&D community to be "washed out" after a period of budget decline, regardless of a subsequent growth. Similarly, a strong self-reinforcing effect kicks in so as to let the R&D community grow very strongly in periods of sustained budget growth.

In other words, the model lacks robustness. This weakness is not highly problematic, however, since the problematique that prompted the model's design and indeed its raison d'etre, was an investigation into whether and when the technology gap can be closed. This limits policy questions to those with increased total European budgets and/or R&D and industrial size and productivity improvements.

In as much as the results appear problematic to the EU in spite of a very optimistic R&D effect from budget growth, it appears that the policy conclusion are robust.

11 FURTHER WORK

Further work could be categorized into four areas. First, the lack of model robustness to budget decrease should be improved upon through weakening the self-reinforcing feedback loop around R&D capacity. Secondly, further attempts should be made so as to get more empirical data for validation and initialisation purposes. Thirdly, a more thorough study of the links between SD and RBV should be made. This could first be done within the confines of the current model, but also other models should be developed and/or investigated. Fourth, the approach used here address an issue in the cross-section of economics, corporate and grand strategy, and political science. While the corporate strategy concepts have been discussed as such, there has been largely a leap of faith that these concepts apply to national and alliance-wide issues. This leap of faith merits further investigation. Also, it must be noted that the current model does not include trans-Atlantic collaboration as a way of speeding up the modernization of European industry or forces

12 SUMMARY

This document has described a System Dynamics model of a value chain that produces advanced weapons. The model merges two distinct traditions of strategic analysis; System Dynamics and the Resource Based View. A simulation model is developed and used to exemplify the approach. In the model, four resource aging chains interact; military men, industrial workers, R&D professionals and defence equipment. The model is initialised to portray both the US and EU defence technology status in 2003. 25 year simulation runs are provided for US and EU base cases, as well as to investigate four EU policy options: Budget policy, Industrial policy, Conscription policy and a Combined policy. It is found that a Combined policy succeeds in cutting in half an initial eight-fold US lead in advanced fieldable military equipment.

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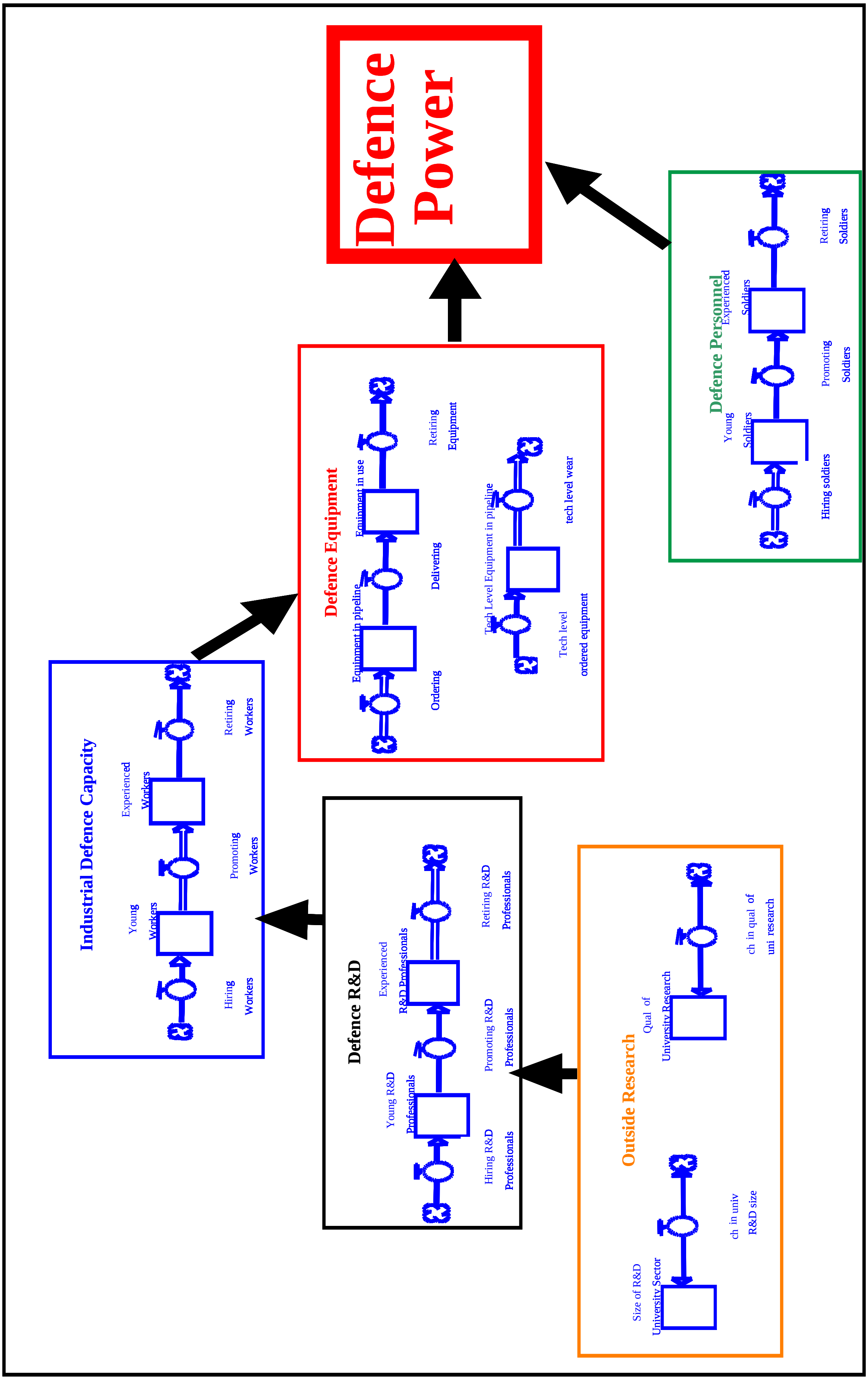
APPENDIKS

A MODEL LISTING

In the following, the US version of the model is documented. The differences between the US and the EU model are different stock initialization values as explained in the table 3 in the main text. Additionally, the EU base and policy cases, with the exception of the mimicking of a US industrial policy all assume a lower industrial productivity than in the US model version.

There are five sectors in the model as shown on the diagram below. These are

- Defence Equipment
- Defence Manning
- Defence R&D
- Defence Industrial Capacity
- Outside Research



Defence Power
Defence Personnel
Young Soldiers
Experienced Soldiers
Hiring soldiers
Promoting Soldiers
Retiring Soldiers
Defence Equipment
Equipment in pipeline
Equipment in use
Ordering
Delivering
Retiring Equipment
Tech Level Equipment in pipeline
Tech level ordered equipment
tech level wear
Industrial Defence Capacity
Young Workers
Experienced Workers
Hiring Workers
Promoting Workers
Retiring Workers
Defence R&D
Young R&D Professionals
Experienced R&D Professionals
Hiring R&D Professionals
Promoting R&D Professionals
Retiring R&D Professionals
Outside Research
Size of R&D University Sector
Qual of University Research
ch in univ R&D size
ch in qual of uni research

US Defence Equipment

In this sector equipment is ordered according to the planned investment budget. Also the technlogy level of equipment in pipeline is accrued according to the current R&D capacity and determines the power of new equipment about to be delivered. Also, the amount of equipment in use - adjusted for the total number of soldiers determines the total nominal military potential. The "power" and "potential" are different performance indicators as the first one gives credit to the most recent technology level and amount of pipelined equipment (but not manpower) and the second credits manpower and (old) equipment stock (and its historical technology level).

*Equipment_in_pipeline(t) = Equipment_in_pipeline(t - dt) + (Ordering - deliveries) * dt*
INIT Equipment_in_pipeline = 385
DOCUMENT: This stock contains all equipment that has been ordered, but not yet delivered. It is initalized to reflect the fact that 2004 US Investments may be estimated at USD 75 billion; allowing for a 15 year life time and a 5 year delivery time makes for 375 billion in pipeline and 1125 billion in use.

INFLOW:
Ordering = Budget(planned_Budget_Investment_and_R&D__fraction-planned_Budget_R&D_fraction)*Industrial_Productivity*
DOCUMENT: Equipment ordering corresponds to the planned investment fraction of the budget (i.e. the Investment AND R&D fraction substracted the R&D fraction)

OUTFLOW:
deliveries = Equipment_in_pipeline/Avg_delivery_time
DOCUMENT: equipment is delivered according to the average equipment delivery time.

*Equipment_in_use(t) = Equipment_in_use(t - dt) + (deliveries - Retiring_Equipment) * dt*
INIT Equipment_in_use = 1186
DOCUMENT: This stock contains all equipment in use. It is initalized to reflect the fact that 2004 US Investments may be estimated at USD 77 billion; allowing for a 15 year life time and a 5 year delivery time makes for 385 billion in pipeline and 1186 billion in use.

INFLOW:
deliveries = Equipment_in_pipeline/Avg_delivery_time
DOCUMENT: equipment is delivered according to the average equipment delivery time.

OUTFLOW:
Retiring_Equipment = Equipment_in_use/Time_to_retire_2
DOCUMENT: equipment retires as the expected retirement time approaches

*Tech_Level_Equipment_in_pipeline(t) = Tech_Level_Equipment_in_pipeline(t - dt) + (Tech_level__ordered_equipment - tech_level_wear) * dt*
INIT Tech_Level_Equipment_in_pipeline = 1

DOCUMENT: This is an indicator that is initialized at 1 and assumes a normal R&D wear. After replacing the aging processes of wearing, additionally added R&D capacity will increase the technology level

INFLOW:
*Tech_level__ordered_equipment = tech_level_wear*effect_of_R&D_capacity_on_tech_level_ordered_equipment*
DOCUMENT: As long as R&D levels are those of the initial situation, tech level of ordered equipment only replaces the normal wear. Changes in the R&D capacity allows additional increase; loss of R&D capacity will lead to insufficient level of tech level of ordered equipment.

OUTFLOW:
tech_level_wear = Tech_Level_Equipment_in_pipeline/Avg_delivery_time
Avg_delivery_time = 5
DOCUMENT: On average, equipment is delivered five years after it is ordered.

avg_tech_level_of_equip_in_use = smth3(Tech_Level_Equipment_in_pipeline,(Avg_delivery_time+Time_to_retire_2/2))
DOCUMENT: The average technlogy level of equipment in use is a third order smooth of the vraible "Tech Level...", with a time delay corresponding to when the equipment was put in service. This latter time delay must first take into account half the expected life time of the equipment, but also the entire delivery time (since Tech Level ... is a variable that refers to equipment in pipeline)

Equipment_ops_cost = Equipment_in_use.08*
DOCUMENT: The annual equipment operating costs have (outside the model) been estimated to 8% of the equipment value. These costs are net of personell costs which are calculated in the "Manning" section of the model. Personell costs are far superior to equipment operating costs.

*new_equipment_power = Equipment_in_pipeline*Tech_Level_Equipment_in_pipeline*
DOCUMENT: This variable indicates the power of the equipment just about to be delivered to the user community. It hence incorporates the latest R&D achievements.

*nominal_mil_potential = Equipment_in_use*Sum_mil_men*avg_tech_level_of_equip_in_use*
DOCUMENT: This variable indicates the potential of very well trained men (young and experienced are counted alike), who employ the total equipment stock, with its average technology level.

Sum_mil_equipment = Equipment_in_pipeline+Equipment_in_use
Time_to_retire_2 = 15
DOCUMENT: On average, equipment lasts for about fifteen years.

effect_of_R&D_capacity_on_tech_level_ordered_equipment = GRAPH(R&D_Capacity/init(R&D_Capacity))

(0.00, 0.944), (0.2, 0.956), (0.4, 0.97), (0.6, 0.986), (0.8, 1.00), (1.00, 1.02), (1.20, 1.03), (1.40, 1.05), (1.60, 1.07), (1.80, 1.08), (2.00, 1.10)
DOCUMENT: comparing present to initial R&D capacity, this variable indicates the degree with which R&D capacity is translated into technology level. Around its operating range, it is quite flat. Above this, R&D capacity has no additional effect; similarly, below this level lack of R&D has no additional negative effect.

US Defence Manning

DOCUMENT:
The manning budget determines the desired manning, and hiring is initiated to close the gap with actual manning (or allows natural retirement to take care of surplus manning). Personell costs are higher for experienced than for your soldiers. Soldier is a term for all military personell, be they uniformed or not - and regardless of rank.

*Old_Soldiers(t) = Old_Soldiers(t - dt) + (Promoting_Soldiers - Retiring_Soldiers) * dt*
*INIT Old_Soldiers = 1250*pers_initiation_dummy*
DOCUMENT: According to NATO documentation, in the 2002 budget year there were 2100 thousand soldiers in the US force. In equilibrium, with average tenure 5 years as young and 20 years as experienced, 80 % of these are experienced, i.e. 1250*1,4 (personell initiation dummy is a dummy variable to enable easier model control of various versions - in particular US and EU ones).

INFLOW:
Promoting_Soldiers = Young_Soldiers/Time_to_promote
DOCUMENT: All soldiers that are recruited are eventually promoted

OUTFLOW:
Retiring_Soldiers = Old_Soldiers/Time_to_retire
DOCUMENT: All soldiers eventually retire

*Young_Soldiers(t) = Young_Soldiers(t - dt) + (Hiring_Soldiers - Promoting_Soldiers) * dt*
*INIT Young_Soldiers = 250*pers_initiation_dummy*
DOCUMENT: According to NATO documentation, in the 2002 budget year there were 2100 thousand soldiers in the US force. In equilibrium, with average tenure 5 years as young and 20 years as experienced, 80 % of these are experienced, i.e. 250*1,4 (personell initiation dummy is a dummy variable to enable easier model control of various versions - in aprticular US and EU ones).

INFLOW:
*Hiring_Soldiers = Retiring_Soldiers*Effect_of_mil_manning_gap_on_hiring*
DOCUMENT: hiring (i.e. recruiting) of soldiers is done to replace those lost to retirement. If there is a surplus or lack of soldiers, there is an attempt to compensate for this. The planned manning budget fraction is what determines desired manning.

OUTFLOW:
Promoting_Soldiers = Young_Soldiers/Time_to_promote
DOCUMENT: All soldiers that are recruited are eventually promoted

budget_manning_cost_fraction = Mil_Manning_ops_costs/Budget
DOCUMENT: This is the -after - the fact, realized budget fraction of manning

*des_mil_manning = mil_men_capacity_multipier*init(Sum_mil_men)*
mil_manning_gap = (des_mil_manning-Sum_mil_men)/Sum_mil_men
Mil_Manning_ops_costs =
*Old_Soldiers*olds_mil_ops_cost+Young_Soldiers*youngs_mil_ops_cost*
olds_mil_ops_cost = .05
DOCUMENT: the annual per head personnell operating cost is derived from total operations costs and total manning under US DoD, given the documented assumptions about young/old soldier relationship.

pers_initiation_dummy = 1.4
DOCUMENT: chosen so as to preserve the data set and model consistency

Sum_mil_men = Old_Soldiers+Young_Soldiers
Time_to_promote = 5
DOCUMENT: On average, untrained soldiers are promoted to the next level after 5 years.

Time_to_retire = 25
DOCUMENT: On average, trained soldiers are retired after 25 years.

youngs_mil_ops_cost = olds_mil_ops_cost
DOCUMENT: There is no difference between the pay for old and young soldiers

Effect_of_mil_manning_gap_on_hiring = GRAPH(SMTH3(mil_manning_gap,1))
(-1.00, 0.01), (-0.8, 0.2), (-0.6, 0.31), (-0.4, 0.45), (-0.2, 0.71), (-5.55e-17, 1.00), (0.2, 1.36), (0.4, 1.67), (0.6, 1.87), (0.8, 1.92), (1.00, 1.99)
DOCUMENT: There is a neutral effect if there is no manning gap; there is a response to a third order smooth if there is a gap. This effect levels at a level where the gap is as high as the current level. The third order smooth effect is used to reflect a decision process that it takes a year on average to implement any hiring based on differences between desired and actual manning levels, and that many instances are involved in this decision.

mil_men_capacity_multipier =
GRAPH(smth3((init(budget_manning_cost_fraction)/budget_manning_cost_fraction),2))
(0.00, 0.01), (0.2, 0.1), (0.4, 0.22), (0.6, 0.36), (0.8, 0.62), (1.00, 1.00), (1.20, 1.58), (1.40, 1.79), (1.60, 1.91), (1.80, 1.96), (2.00, 2.00)
DOCUMENT: There is a neutral effect if actual and initial budget gaps are identical; there is a response to a third order smooth if there is a gap. This effect levels off at a level where the new fraction is twice as high as the initial level. The third order smooth effect is used to reflect a

decision process that it takes two years on average to implement any hiring based on differences between desired and actual budget levels, and that many instances are involved in this decision.

US Defence R&D

Planned budget for R&D determines desired R&D capacity. Gaps in this capacity translates into hiring or natural attrition. Attrition is however modified in the case that realized costs are different from those budgetted to reflect liquidity constraints.

*Experienced_R&D_Professionals(t) = Experienced_R&D_Professionals(t - dt) + (Promoting_R&D_Professionals - Retiring_R&D_Professionals) * dt*
*INIT Experienced_R&D_Professionals = 0.55*5*990/6*

DOCUMENT: the initialization of R&D professionals reflects the promotion chain so that 5/6 are experienced. Intial level is estimed to 990 using the assumed average pay and the Investment budget net of equipment purchase (according to NATO documents). These 990 (*1000) R&D professionals did give a too high R&D cost fraction and so was reduced by the "0.55" dummy variable.

INFLOW:
Promoting_R&D_Professionals = Young_R&D_Professionals/Time_to_promote_4
DOCUMENT: all newly hired R&D professionals stay "rookies" during their "promotion time" after which they "graduate" to the next "experienced" level

OUTFLOW:
*Retiring_R&D_Professionals = if R&D_surplus > 0 then Experienced_R&D_Professionals/Time_to_retire_4 else Experienced_R&D_Professionals/(Time_to_retire_4*0.1)*
DOCUMENT: if there is an R&D surplus, there is money to lengthen senior R&D personel's working contracts,so as to reduce retirement to 1/10 of what is normal

*Young_R&D_Professionals(t) = Young_R&D_Professionals(t - dt) + (Hiring_R&D_Professionals - Promoting_R&D_Professionals) * dt*
*INIT Young_R&D_Professionals = 0.55*990/6*
DOCUMENT: the initialization of R&D professionals reflects the promotion chain so that 1/6 are inexperienced (i.e. young). Intial level is estimed to 990 using the assumed average pay and the Investment budget net of equipment purchase (according to NATO documents). These 990 (*1000) R&D professionals did give a too high R&D cost fraction and so was reduced by the "0.55" dummy variable.

INFLOW:
*Hiring_R&D_Professionals = if R&D_surplus > 10 then Retiring_R&D_Professionals*Size_of_R&D_University_Sector*Effect_ofdev_manning_gap_on_hiring*4 else if R&D_surplus> 0 then Retiring_R&D_Professionals*Size_of_R&D_University_Sector*Effect_ofdev_manning_gap_on_hiring else 0*

DOCUMENT: If there is a substial economic R&D surplus, then there is much hiring. If there is little surplus there is less, but still some hiring. If there is a lack of funds, there is no hiring.

OUTFLOW:
Promoting_R&D_Professionals = Young_R&D_Professionals/Time_to_promote_4
DOCUMENT: all newly hired R&D professionals stay "rookies" during their "promotion time" after which they "graduate" to the next "experienced" level

*des_dev_manning = dev_men_capacity_multipier*init(R&D_Capacity)*
DOCUMENT: Desired R&D manning reflects the capacity multiplier

dev_manning_gap = (des_dev_manning-R&D_Capacity)/R&D_Capacity
DOCUMENT: The fractional R&D manning gap

*R&D_Budget = Budget*planned_Budget_R&D_fraction*
DOCUMENT: The (planned) R&D budget reflects to planned Budget and the planned R&D fraction

*R&D_Capacity = (Experienced_R&D_Professionals*2+Young_R&D_Professionals)*R&D_Productivity*
DOCUMENT: It is assumed that the experienced R&D professionals are as productive as the youbg ones.

R&D_Costs = (Experienced_R&D_Professionals(olds_mil_ops_cost)*2+Young_R&D_Professionals*(youngs_mil_ops_cost)*2)*
DOCUMENT: R&D per person costs are double those of the soldiers

*R&D_Productivity = Ambient_R&D_Productivity*R&D_Ec_of_Scale*
DOCUMENT: The Defence R&D productivity reflects the size of the Defence R&D community through the "R&D economy of scale" variable, but also through the societal "Amibent R&D Productivity"

R&D_surplus = R&D_Budget-R&D_Costs
DOCUMENT: If the R&D sector is not large enough to generate sufficient costs, i.e. to use its budget, there is a surplus

real_r&d_fraction = R&D_Costs/Budget
DOCUMENT: This is the realized fraction the the budget that is spent by the Defence R&D community through its employees.

Time_to_promote_4 = 5
DOCUMENT: on average, it takes 5 years to be "promoted" from a newly hired to "expert R&D" professional. The time constant is derived logically

Time_to_retire_4 = 25
DOCUMENT: on average, it takes 25 years to be "leave the ranks" once promoted to "expert R&D" professional. The time constant is derived logically

dev_men_capacity_multipier = GRAPH(smth3((planned_Budget_R&D_fraction/init(planned_Budget_R&D_fraction)),2))
(0.00, 0.01), (0.2, 0.1), (0.4, 0.22), (0.6, 0.36), (0.8, 0.62), (1.00, 1.00), (1.20, 1.58), (1.40, 1.79), (1.60, 1.91), (1.80, 1.96), (2.00, 2.00)
DOCUMENT: The third order smooth is used to reflect a multi-tierd decision process in transferring R&D insight to and through the industrial defence community. Similarly the 2 year constant is chosen to reflect the time this process takes on average.

Effect_ofdev_manning_gap_on_hiring = GRAPH(SMTH3(dev_manning_gap,1))
(-1.00, 0.01), (-0.8, 0.2), (-0.6, 0.31), (-0.4, 0.45), (-0.2, 0.71), (-5.55e-17, 1.00), (0.2, 1.36), (0.4, 1.67), (0.6, 1.87), (0.8, 1.92), (1.00, 1.99)
DOCUMENT: The third order smooth is used to reflect a multi-tiered decision process in transferring to and through the R&D hiring. Similarly the 1 year constant is chosen to reflect the time this process takes on average.

R&D_Ec_of_Scale = GRAPH((Experienced_R&D_Professionals+Young_R&D_Professionals)/(init(Experienced_R&D_Professionals)+init(Young_R&D_Professionals)))
(0.00, 0.3), (0.2, 0.57), (0.4, 0.77), (0.6, 0.88), (0.8, 0.96), (1.00, 1.00), (1.20, 1.06), (1.40, 1.09), (1.60, 1.12), (1.80, 1.16), (2.00, 1.17)
DOCUMENT: This non-linearity reflects is initialized of the size of itself. Once the R&D community shrinks, there it becomes less effective. Conversely, there are tapering benefits of a larger R&D capacity.

US Industrial Defence Capacity
This sector shows how the planned budget transaltes into desired industrila capacity and how this capacity is translated into need for workers. An eventual gap between required industrial capacity translates into hiring of workers (or allowing natural retirment to take care of excess capacity)

*Experienced_Workers(t) = Experienced_Workers(t - dt) + (Promoting_Workers - Retiring_Workers) * dt*
*INIT Experienced_Workers = 5*1400/6*
DOCUMENT: 5/6 of the estimated 1400 (thousands) defence industrial workers are experienced. 5/6 reflects an initial balance between the 5 years in the "young" worker pool and 25 years in the "experienced"

INFLOW:
Promoting_Workers = Young_Workers/Time_to_promote_3

OUTFLOW:
Retiring_Workers = Experienced_Workers/Time_to_retire_3

*Young_Workers(t) = Young_Workers(t - dt) + (Hiring_Workers - Promoting_Workers) * dt*
INIT Young_Workers = 1400/6
DOCUMENT: 1/6 of the estimated 1400 (thousands) defence industrial workers are experienced. 1/6 reflects an initial balance between the 5 years in the "young" worker pool and 25 years in the "experienced"

INFLOW:
*Hiring_Workers = Retiring_Workers*Effect_of_industrial_capacity_gap_on_hiring*

OUTFLOW:
Promoting_Workers = Young_Workers/Time_to_promote_3

*des_industrial_capacity = industrial_capacity_multipier*init(Industrial_Output__Capacity)*
DOCUMENT: Desired Industrial Capacity equals the initial Industrial Capacity times the "mulitiplier"

*Industrial_Manning__ops_costs = (Experienced_Workers*olds_mil_ops_cost*1.1+Young_Workers*youngs_mil_ops_cost*1.1)*
DOCUMENT: The personell costs here reflect the fact that industrial workers on average make 10 % more than the soldiers

*Industrial_Output__Capacity = (Experienced_Workers+Young_Workers)*Industrial_Productivity*
DOCUMENT: Output Capacity is measured in billion dollars per year and reflects the total number of workers and their productivity

*Industrial_Productivity = R&D_Productivity*Industrial_Ec_of_Scale*
DOCUMENT: The Industrial productivity applies to the worker community and partly reflects the size of this community, and partly reflects the R&D productivity

industrial__capacity_gap = (des_industrial_capacity-Industrial_Output__Capacity)/Industrial_Output__Capacity
DOCUMENT: The (percentage) gap between desired and actual Industrial Output Capacity

Time_to_promote_3 = 5
DOCUMENT: On average, it takes 5 years for a worker to gain enough experience to "graduate" to the next level

Time_to_retire_3 = 25
DOCUMENT: On average, people stay experinced until they retire after 25 years.

Effect_of_industrial_capacity_gap_on_hiring = GRAPH(SMTH3(industrial__capacity_gap,1))
(-1.00, 0.01), (-0.8, 0.2), (-0.6, 0.31), (-0.4, 0.45), (-0.2, 0.71), (-5.55e-17, 1.00), (0.2, 1.76), (0.4, 3.24), (0.6, 3.60), (0.8, 3.94), (1.00, 4.00)

DOCUMENT: a third order smooth is chosen so as to reflect a multi-level process. 1 year time constant is chosen so as to reflect hiring processes in the industry as a whole. If there is no capacity gap, then this effect is neutral. It levels of at 100 % capacity gap, where the effect is to forfold any present indication of hiring.

industrial_capacity_multipier = GRAPH(smth3(planned_Budget_Investment_and_R&D__fraction/init(planned_Budget_Investment_and_R&D__fraction),2))
(0.00, 0.01), (0.2, 0.1), (0.4, 0.22), (0.6, 0.36), (0.8, 0.62), (1.00, 1.00), (1.20, 1.58), (1.40, 1.79), (1.60, 1.91), (1.80, 1.96), (2.00, 2.00)
DOCUMENT: a third order smooth is used to reflect a multitude of related decision processes. a 2 year time constant is used to reflect the delay in modifying decisions. If the investment budget is greater than the initial one, then there is the creation of an impetud to increase the size of the industrial base

Industrial_Ec_of_Scale = GRAPH((Experienced_Workers+Young_Workers)/(init(Experienced_Workers)+init(Young_Workers)))
(0.00, 0.02), (0.2, 0.47), (0.4, 0.81), (0.6, 1.04), (0.8, 1.13), (1.00, 1.20), (1.20, 1.26), (1.40, 1.29), (1.60, 1.29), (1.80, 1.30), (2.00, 1.31)
DOCUMENT: If the size of the industrial capacity, i.e. largely the size of the total workforce, there are scale economy potentials THAT ARE ASSUMED REALIZED

US Outside Research
*Qual_of__University_Research(t) = Qual_of__University_Research(t - dt) + (ch_in_qual_of_uni_research) * dt*
INIT Qual_of__University_Research = 1
DOCUMENT: muted

IN/OUTFLOW:
ch_in_qual_of_uni_research = 0.0
DOCUMENT: muted

*Size_of_R&D_University_Sector(t) = Size_of_R&D_University_Sector(t - dt) + (ch_in_univ_R&D_size) * dt*
INIT Size_of_R&D_University_Sector = 1
DOCUMENT: muted

IN/OUTFLOW:
ch_in_univ_R&D_size = .0
DOCUMENT: muted

*Ambient_R&D_Productivity = Qual_of__University_Research*SQRT(Size_of_R&D_University_Sector)*
DOCUMENT: muted

Not in a sector

Budget = 330((1+growth)^year)*

equipment_ops_cost_fract = Equipment_ops_cost/Budget

equipm_pr_pers = Sum_mil_equipment/Sum_mil_men

growth = 0

investm_pr_pers = Ordering/Sum_mil_men

planned_Budget_Investment_and_R&D__fraction = max(0.0,((budget-(Equipment_ops_cost+Mil_Manning_ops_costs))/Budget))

planned_Budget_R&D_fraction = max(0.0,(planned_Budget_Investment_and_R&D__fraction-(Industrial_Manning__ops_costs/Budget)))

planned_investment_budget = Budget(planned_Budget_Investment_and_R&D__fraction-planned_Budget_R&D_fraction)*

year = time