The Economics of the Revolution in Military Affairs

Paul Dunne,
University of the West of England

Maria Garcia-Alonso,
University of Kent

Paul Levine,
University of Surrey

Ron Smith,
Birkbeck College, London

May 2003

Preliminary version of a paper prepared for the 38th Economic Policy Panel, Rome 17-18 October 2003

Corresponding author Smith: R.Smith@bbk.ac.uk. The other authors are grateful to the ESRC for support under grant R000239388. Copies of the project papers can be found at http://carecon.org.uk/Armsproduction/.

Contents:

1. Introduction

War and economics have been entwined since the origins of economics as a discipline[1]. There are three strands to this linkage: consequences, causes and conduct of war. The first strand is the need to understand the economic consequences of War and adjust policy accordingly. From Ricardo on the Bullion Controversy, provoked by the suspension of the Gold Standard during the Napoleonic Wars, through to Keynes, on how to pay for the Second World War, managing the war economy has been a central question[2]. Within much of the poor world, particularly Africa, civil wars are a major cause of economic dislocation and the international financial institutions are struggling to come to terms with this linkage. In particular, managing post-conflict reconstruction and providing incentives for combatants to return to civilian life has proved difficult[3]. The wars themselves also provide natural experiments and exogenous instruments for testing theories. The second strand is the need to understand the causes of conflict, particularly when there may be economic elements in those causes. Such economic elements include the liberal view that trade promotes peace; the mercantilist-Leninist view that war is the continuation of economic competition by other means; and the explanation of civil war in poor countries as often driven by attempts to control natural resources like oil or diamonds[4]. The third strand is the use of economic analysis to improve the effectiveness of the prosecution of war. This runs from Adam Smith's discussion of the relative effectiveness of standing armies and militias to twentieth century applications of economics, and other types of applied mathematics, to develop effective military tactics and strategies. The application of game theory to nuclear targeting is a classic example; von Neumann was the model for Dr Strangelove.

More recently the end of the Cold War saw major changes in the economics of preparing for war. Objective functions changed as the Soviet threat disappeared and new threats appeared. Budget constraints changed with large cuts in military expenditure during the 1990s. Production functions changed with major innovations in military technology. These in turn produced changes in the structure of the arms

[1] Anderton (2003) provides a recent review
[2] Indeed Stone(1988) refers to work by Gregory King in 1695 on the question of how long England could sustain the war against the league of Augsburg.
[3] See Harris (1999)
[4] See Kaldor (1999) and Collier (2000)

industry, the structure of the armed forces and the costs and benefits and thus the probabilities of different types of war. During the 1990s two concepts became central to military discourse: The Revolution in Military Affairs, RMA, the term used for the way that changes in technology were transforming fighting, and Asymmetric Warfare, the term used for the way that opponents would respond to a dominant military power by fighting in ways that the dominant power did not expect or prepare against. Neither concept is new; there have been a series of revolutions in military technology (Kirkpatrick, 2000) and attacking in ways that your opponent did not expect has been the basis of strategy since at least Sun Tzu in the fourth century BC (Newman, 2000). However, there has been considerable dispute about exactly how each should be defined in the current context. Definitions of the RMA tended to emphasise the way that improvements in information technology, precision targeting and smart munitions created the possibility of a new form of network-centric warfare. Definitions of asymmetric warfare have emphasised asymmetries in technology, what each side fights with; asymmetries in tactics, how each side fights; or asymmetries in the stakes, the costs of defeat to each side. Despite having massive technological and military superiority; the US withdrew from Lebanon in 1983 after a suicide bombing killed 241 troops and from Somalia in 1993 after a battle in Mogadishu, in which television covered the brutal treatment of two American corpses and one injured prisoner. In neither country did the US have large stakes. Much of the military discussion prior to the coalition attack on Iraq in Spring 2003 centred on the extent to which Iraq could neutralise technological superiority by using guerrilla tactics and urban warfare.

This paper discusses some aspects of these concepts emphasising the economic issues involved and economic models that we have developed to analyse the changes[5]. We will draw on comparisons between the putative New Economy of defence, the RMA and asymmetric warfare, and the putative New Economy in Civilian life, where changes in technology transformed production and distribution making dominant incumbents, like IBM, vulnerable to attack by initially small competitors, like Intel and Microsoft, who followed different strategies. In the new economy literature it is common to distinguish incremental and disruptive technological change. Under the

[5] Technical details are available in two associated papers: Military Procurement, Industry Structure and the Revolution in Military Affairs and Managing Asymmetric Conflict, and brief outlines of the models are given in an appendix.

former competition proceeds down well established product and process technological trajectories. Under the latter the industry and market is completely transformed. We will make a similar distinction with the early part of the paper emphasising incremental changes in military technology, the latter disruptive change.

Throughout this paper we will maintain a rational actor model that assumes that agents, states or non-state actors, acquire armed forces because of their utility in combat. The decision maker perceives potential threats, assesses the military capabilities required to counter the threat, determines the force structure that will provide those military capabilities and subject to a budget constraint determines the optimal force structure. This model captures important aspects of military planning for nations with recent combat experience or hostile neighbours, US, UK, France, Russia, Greece, Turkey, etc. It probably does not capture the experience of those nations who do not expect their armed forces to fight. Defence budgets in such countries have different functions.

The military distinguish three levels of analysis: the strategic, the conduct of the war as a whole; the operational, the conduct of a campaign; and the tactical, the conduct of a particular engagement with the enemy, e.g. a battle. Since the meaning of strategy is different between the military and game theorists, who use it to refer to state contingent moves, we will always refer explicitly to military strategy, rather than strategy, when we refer to the planning of a war as a whole.

Section 2 provides some background on the current military environment. Section 3 examines the economic dimensions of that environment. Section 4 provides a model of the interaction of procurement, technology and market structure. Section 5 discusses asymmetric warfare. Section 6 models managing asymmetric conflict. Section 7 has some conclusions.

2. The Military Environment

There have been a variety of changes that have transformed the global military environment over the last decade. The most obvious development is that US preponderance has grown. In 2001 SIPRI estimated that the US accounted for 36% of world military expenditure of $839bn. The combined expenditure of next four largest spenders, Russia, France, Japan and the UK, was about half that of the USA. It requires the combined total of the next nine largest spenders to match the US. This is a conservative estimate; on other treatments of exchange rates, it requires the next fifteen to twenty states to match the US. Furthermore US spending is growing, whereas for most of the rest military expenditure is not growing.

Fixed costs of R&D for major systems continues to escalate. This is true for the platforms, for the infrastructure (e.g. satellites, strategic airlift) and for the information systems needed to support network-centric warfare. It means that all but the US, face structural disarmament as they are unable to afford the fixed costs needed to replace conventional military capability with modern systems comparable to the US. This is a particular problem for the minor powers who have broader military aspirations, in particular the other permanent members of the Security Council: China, France, Russia and the UK. It also becomes difficult for the US to work with other nations since their systems (e.g. IFF (Identification Friend or Foe) to prevent friendly fire casualties) are not interoperable.

The costs of military technology are high even for the US, as exemplified by the projections for the costs of missile defence, and it, like other countries, has tried to use commercial practices and products to reduce costs. This has had mixed success and is discussed further below. The traditional method of sharing fixed costs, collaboration, has, however, become less effective, with failures and difficulties on a large number of European projects, such as Eurofighter, its main weapon Meteor and the Airbus A400M transport. There has, however, been an increasing internationalisation of arms production, through joint ventures and take-overs, as well as an increase in the use of civil components within weapons systems (SIPRI, 2002).

Since the US appears invulnerable in the type of warfare it has chosen to invest in, adversaries have an incentive to resort to other types of warfare: asymmetric warfare, which can exploit other vulnerabilities of the US and its allies. The bombing of the USS Cole in Yemen in 2000 and the attack on the World Trade Centre on September

11 2001 demonstrated US vulnerability to certain sorts of asymmetric attack. This suggests that while governments have been trying to commercialise the military, to cut costs, their opponents have been trying to militarise the commercial, to produce new weapons. Fertiliser and fuel oil make explosives, commercial aircraft make missiles. The emergence of dual-use technology is a double-edged sword for governments: procurement costs may well fall, but the weapons become more readily available to terrorists. Not only are the technologies for weapons of mass destruction (WMD) - nuclear, biological and chemical - inherently dual use, but new information technologies have potentially military applications, e.g. they can be used to maintain international terrorist networks and to exploit vulnerabilities in the infrastructure of the US and its allies.

Conventional military capability still retains its utility for antagonists in regional rivalries: India-Pakistan; Greece-Turkey, North and South Korea etc, though even in these cases there are incentives to acquire WMD. Inter-state war is, however, rare while it is intra-state war is common. On the Gleditsch et al. (2002) measures, of the 225 armed conflicts over the period 1946-2001 only 46 were between states. Inter-state wars are also shorter, so at any time the vast majority of wars are intra-state. Within countries traditional military capability may be ineffective in maintaining order and in consequence states in many parts of the world have failed; being unable to maintain a monopoly of the legitimate use of force and provide security of life or property.

3. Economic Dimensions of Conflict

3.1 Objective Functions

Most economists have followed Adam Smith in emphasising people's propensity to truck barter and exchange. But why truck barter and exchange when you can rob, pillage and loot? Again most economists have followed Smith in dealing with this problem by assuming exogenous provision of property rights. That there is a sovereign or state whose duties include protecting the society from the violence or invasion of other societies and establishing a legal system which administers justice and enables exchange and investment to proceed with security[6]. Under these assumptions robbing, pillaging and looting are excluded from the set of possible economic actions.

This may be a reasonable first approximation for some times and places, but is certainly not for others, including much of the world today. However, there is now a fairly large literature concerned with endogenous property rights. This literature has two strands. In the first, despite the absence of absence of a legal system social institutions arise to fulfil the same functions, primarily because of the benefits of maintaining relationships in repeated games. In this strand agents do not allocate resources to preparations for conflict. Dixit (2002) provides many examples and models of such cases. In the second strand agents allocate resources to preparation for conflict as well as to production and trade. In terms of Dixit's example, in the first strand the Mafia provides information, turning one-off games between isolated traders into repeated games between each trader and the Mafia. In the second strand, the Mafia provides enforcement, inflicting punishment on anyone who cheats. Enforcement requires the mafia to allocate resources to weapons and to investment in human capital to develop the specialised skills required. It is this second strand that concerns us.

When conflict is an option, the resulting distribution of property reflects agents' ability to protect their resources from others or steal resources from others. The simplest models have individuals who can allocate their time between investment in growing food, stealing food from others and defending the food they have from theft by others. An early example is the work of Earl Thompson (1974, 1979), who looked at the equilibrium distribution of capital among nations, but the literature has grown rapidly in recent years. Typically the models will have a number of agents each subject to a budget constraint, with production possibilities for various goods, including military ones and exchange possibilities. This literature has been motivated by a variety of different concerns: attempts to develop better theories of the emergence and nature of the state McGuire and Olson (1996); attempts to understand civil wars, Collier (2000), Gershenson et al. (2000), Sambanis (2002); by a desire to

[6] Coloumb (1998) disusses Smith's writing on defence economics..

integrate the models of production and exchange with models of conflict and struggle, Rider (2002); to understand intervention in conflicts by third parties (Siqueira 2002); by a concern with issues of terrorism, organised crime, post-conflict demobilisation and reconstruction, etc.

A common formulation is that the objective function of a state, say welfare, depends on consumption and security, a function of your own and an opponents armed forces. Welfare is maximised subject to a budget constraint, thus determining the optimal level of armed forces. Security can have many levels depending on what the threat is. From 1945 to 1989 the central concern was the potential conflict between NATO and the Warsaw Pact; a classic arms race between two militarised powers. In many parts of the world, such arms races continue to be important. Other countries face internal threats against which military preparations are effective. These are mainly poor countries, but also include Spain and the UK. Some countries, such as the US feel threatened by external non-state actors. Some states want to project power to intervene for human rights or other ways, while some, such as the small European powers, have no obvious threats but retain military forces as a general insurance policy. Given US military dominance there is a natural international concern about what its security objectives in fact are.

3.2 Production Functions

In the literature which deals with potential conflict with an identified enemy the analogy to the production function is the conflict success function, CSF: the inputs are the investments in fighting efforts of the two sides and the outputs are their relative degree of success in the conflict: either the probability of winning or the share of the pie that goes to each side. There are two main functional forms used in which success depends either on the ratio of the forces or the difference of the forces. Hirschleifer (2000) provides an excellent discussion of CSF, with many military and non-military examples, which captures the spirit of the literature.

It is worth starting with what Hirschliefer calls the micro-technology of conflict. The classic work is the Lanchester (1916) model of how the quality and numbers on each side influenced the evolution of particular types of battle. Consider, f_A fighting units of riflemen of one side in line, facing f_B of the other side, each side starts aimed firing at the other with attrition rates q_A and q_B (these can be thought of as measures of relative quality, which will depend on the product of the probability of a kill and the rate at which they can fire). The number of A riflemen who are killed is determined by the number of B troops shooting and their accuracy, similarly for B. Notice that as one of the A troops are hit, this reduces the casualties B is suffering enabling them to hit more A troops. Solving these equations the initial force level at which the sides are equally matched, in that in combat they would reach zero forces at the same time, is given by the quality times the number of troops squared. This suggests measuring relative military strength by the ratio of the qualities times the square of the ratio of the numbers. The exponent, the square in this case, is often called the Lanchester coefficient and, as discussed below, can take different values depending on the type of conflict. Another example of the derivation of an implicit CSF using micro-foundations from the dynamics of a battle is Intriligator (1976), who considers nuclear exchanges. It may appear that a limitation of such models is that the stronger side must ultimately wipe out the weaker, so there is no way to scale the degree of success. This only seems true because the description of the battle is incomplete, it describes the evolution of forces, not how the battle ends. For instance, having seen how the battle is going generals may be able to retreat and regroup; or forces may break and run after having taken a certain percentage of casualties (in which case a smaller more determined force may win).

The nature of the batle determines the Lanchester coefficient, which measures the diminishing returns to scale to large forces. The number of A killed depends on the number of B forces to the power λ and the number of A forces to the power $1-\lambda$. Above the number of A riflemen killed just depends on the number of B forces, so $\lambda=1$. The case of $\lambda=1/2$ corresponds to the case of individual duals or un-aimed positional fire. In this case military strength is a function of the ratio of numbers, rather than the square of the ratio of numbers. As discussed by Hirschliefer the larger λ the more decisive the combat tends to be. The case of $\lambda=0$ corresponds to the case, where the sides did not engage, but forces steadily decay either because of disease, common in the past, or logistics failures, a major problem now. The q_i then measured the two sides relative ability to maintain their force structure.

There is a vast military literature on success in battle, but relatively little econometric work on conflict success functions. An exception is Rotte and Schmidt (2002), who use a data set of 625 battles 1600-1973 to estimate an equation to explain victory by the attacker in battle: a zero one dependent variable. The explanatory variables include the force-ratio of the two sides and expert assessments of relative advantages in leadership, surprise, morale, logistics and intelligence which were significant; and training, defensive posture, and technology, which were not significant. The estimates bring out the importance of the intangibles of battle: leadership, morale, etc; but even with all these included the fit is low, with a pseudo R squared of less than a third: outcomes of battles are relatively unpredictable even with the benefit of hindsight. As they point out there is a sample selection problem. We only observe a battle when both sides think they have a reasonable chance of winning, otherwise it does not take place.

Most of the analysis either treats aggregate military strength as a single aggregate, or distinguishes just between labour and capital, members of the armed forces and their equipment. In fact determining the optimal force structure involves four main choices for both labour and capital. The first choice is the number of varieties of types of forces: army, navy, airforce, each made up of specialised types of soldiers, sailors and airmen, each with distinct roles and associated equipment. There is some substitution between these varieties, a target may be destroyed by a tank shell, a bomb dropped from an aircraft or a cruise missile launched from a submarine. The second choice is the quality of those forces, determined by R&D for equipment and training for labour. The third choice is the quantity of each. The final choice is whether they are obtained domestically or from abroad. This choice is primarily important for equipment, where security of supply for spares in case of conflict is often important, but does occur for labour for those countries that use foreign soldiers, such as the UK with the Ghurkas and France with the Foreign Legion.

3.3 Cost Functions

Weapons are very R&D intensive: small performance advantages over the enemy can translate into victory, but getting that last 5% of performance is very expensive. This produces a race to improve technology and the real cost of weapons has grown at between 6 and 10% per annum between generations. Because the weapons are so expensive the gaps between generations get longer and as a result much military equipment is very old, e.g. the B52, still being extensively used, is a 1950s bomber with newer avionics and weapons.

The RMA is potentially the latest of a sequence of technological changes that have transformed the military, Kirkpatrick (2000). Such revolutions usually also change the balance of power, as one group or country adopts the new technology faster than their antagonists and use it to change the way war is fought. The technological changes can involve new products, like the tank, or new processes, forms of organisation, like Blitzkreig, that make better use of existing products. In the military, process innovation tends to be much slower than product innovation, particularly in peace-time. In general, new technologies have been most effective when used in ways that are unexpected by the enemy and have often been associated with the rise of new revisionist powers e.g. the Japanese defeat of the Russians in 1905, through the use of the latest technology and a more effective strategy. Some military revolutions concentrate power, because the equipment is so expensive and specialised that only an elite can afford it; the rise of the armoured knight in their siege-proof castles, for instance. Other revolutions disperse power as they put cheap capability into mass hands; the guns that displaced the knights and castles (Freedman,1994;Parker, 1988).

Old economy military technology was very centralising; rapid cost growth between generations of weapons means that almost nobody, not even the US, can afford it. Most military equipment is obsolete in commercial terms before it enters service, because it takes on average seven years to develop and deliver it. Eurofighter, not yet in service, is based on early 1980s designs; and when it enters service, it will do so without its main missile, Meteor, which is mired in collaborative politics. Current fighting power is very much old economy, the question is whether this will change and what a new economy military might look like .

It is worth comparing the new military and civilian economies in terms of some core characteristics. New-economy industries tend to have high fixed costs but low marginal production costs. Software is expensive to develop but cheap to produce in quantity. They tend to have network effects, the more people who use the product the more effective it is. Innovation tends to be a series of winner-take-all races. At any moment in time a single firm, which produced the killer application, tends to dominate the market; but when innovation is rapid their dominance is precarious: as Netscape fell to Microsoft and Yahoo fell to Google. Bresnahan and Greenstein (1999) discuss some of these issues. Most weapons production does not show these characteristics. Although they do have high development costs, they are also so costly to produce that they are limited to small batches with long gaps between generations. A further consequence is that innovation is slow. The defence industry is fragmented and the market leaders are the same old firms who have been producing weapons for decades. The arms industry is still waiting for the killer applications that displace most of the competition, typical of the new economy.

There are some new economy elements. The Global Positioning System, GPS, is a system of military satellites that has spawned a myriad of commercial applications. The system was expensive, but receivers are cheap. GPS was crucial in the 1991 Gulf War. For the first time in desert warfare, commanders could rely on soldiers knowing where they were. The wide availability of GPS allowed the allied commanders to use tactics that would have been impossible without it. Nearly all the friendly fire incidents involved vehicles without GPS. GPS was widely available because there was a commercial industry from which the military could quickly buy the GPS receivers that they needed to equip their vehicles. Such symbiosis between the commercial and the military will be central to any new economy armaments, but will raise issues as to who has control of the technology.

Cost is central to the RMA. Mathews and Treddenick (2000) in their collection of essays on managing the RMA conclude `ultimately, however, managing the RMA means finding the resources to make it a reality' (p97) and, `a technical revolution is only feasible if it is affordable' (p4). Some spreadsheet simulations for NATO countries provide the conclusion: `Given the RMA is assumed to be characterised by increasing equipment intensity, it appears that no country, including the US, would be able to undertake the RMA without either significant reductions in personnel numbers or significant increases in defence budgets, or some combination of both' (p113). On the assumption that real defence budgets and personnel are constant, wages grow in line with the economy, there is no real growth in the cost of equipment (a very implausible assumption) and that the equipment will have a useful life of 15 years, equipment per service personnel in 2015 would be just over 20% lower in the US and almost 40% lower in the UK.

Government's attempts to make defence more affordable include acquisition reform; use of commercial-off-the-shelf, COTS, technology; improved logistics and the like. These, it is hoped, will generate a revolution in defence business affairs which will pay for the RMA. The history of past procurement reform does not encourage this optimism by the military, but maybe this time it will be different**.** A recurring theme in military procurement reform is the attempt to learn from the commercial world, where new technology generate low production costs and high volumes rather than as in the military with high production costs and low volumes. In the commercial world change is rapid, not slowed by long replacement cycles, and most equipment is relatively new compared with much military equipment. The thrust of reform has been to commercialise the military, by importing private sector practices into military organisation. However, because military time-horizons are so long, much of the equipment is old and there are major problems of obsolescence, since commercial markets, particularly in electronics, do not support systems and devices designed to last for decades. The Department of Defense has a special programme DMEA (Defense Microelectronics Activity) for the manufacture of replacement parts no longer supported by the commercial market.

During the 1991 Gulf War 9% of the ordinance dropped consisted of `smart' (precision-guided) munitions. In Kosovo in 1999, the figure had risen to 29%, but cloud cover hindered employment of the laser guided types. In Afghanistan it was between 60 and 70%, with a large proportion of these being standard dumb bombs, with strap-on guidance kits, that allowed high accuracy from safe bombing heights. In the 2003 Iraq war it was over 90%. Both the strap-on kits, JDAM (the GPS guided Joint Direct Attack Munition) and WCMD (Wind Corrected Munitions Dispensers) were cheap in military terms because they used more commercial development programmes and commercial components. It had been estimated that under traditional acquisition programmes JDAM would cost $68,000 each. A new system, mandating a maximum price, was used and the final cost was about $18,000 each, Lorel et al. (2000). Subsequently with competition and dual sourcing the price fell to about $12,000. Of course JDAM is only useful if you already have the legacy systems: B52s and dumb bombs.

3.4 Budget Constraints.

According to WMEAT (2000), world military expenditures peaked at $1360 billion in the mid 1980s, fell gradually at first with improving east-west relations, then rapidly after the disintegration of the Soviet Union to $823 billion in 1997, remaining constant or perhaps starting to rise thereafter, all figures in 1997 dollars. Table 1 from WMEAT (2002) presents data on military expenditure in 1989 and 1999 for the top 15 spenders in 1999 and the world as a whole. It also gives military expenditure as a share of GDP, a rough measure of the burden, and military expenditure per member of the armed forces, a rough measure of the capital-intensity (physical and human) of military preparations.

Table 1

Top 15 Military Spenders in 1999

			1999	
Country	ME1989*	ME1999*	ME/GNP%	ME/AF**
US	382000	281,000	3	189000
China	54400	88900	2.3	37000
Japan	36200	43200	1	180000
France	43500	38900	2.7	92400
UK	48300	36500	2.5	167000
Russia/USSR	381000	35000	5.6	38900
Germany	42900	32600	1.6	98500
Italy	23200	23700	2	60600
Saudi	18400	21200	14.9	112000
Taiwan	7520	15200	5.2	41000
S Korea	9220	11600	2.9	17400
India	7720	11300	2.5	8670

Turkey	4020	9950	5.3	12600
Brazil	7150	9920	1.9	33100
Israel	7760	8700	8.8	50300
World Total	1310000	852,000	2.4	40100

*Millions of 1999 dollars

**1999 dollars

Procurement of weapons also fell sharply with SIPRI (2000) estimating that arms production (domestic demand plus exports minus imports) in 1997 was 56% of its 1987 level in the US, 77% in France and 90% in the UK.

At the same time as procurement fell so did R&D in most countries, the main exception being the massive growth in Spain. By 1998 the clear difference in the R&D effort being made in the US, UK and France remained, but Spain had reached R&D expenditures of over 10% of military spending and nearly 30% of government R&D. The US R&D expenditure continued to dwarf the other countries, spending more than ten times the amount of the UK and France. Total R&D expenditure fell by 29% over the period.

Table 2: Government Expenditure on Military R&D

			% Change	% milex	% Gov R&D
Country	1987	1998		1998	1998
USA	56200	39800	-29.2	15	54
UK	5320	3890	-26.9	10	39
France	5750	3550	-38.3	9	25
Germany	2110	1560	-26.1	5	9
Japan		1110		3	5
Spain	130	950	630.8	13	29
Italy	490	180	-63.3	1	3
Australia	170	150	-11.8	2	7
Sweden	650	140	-78.5	3	7
Canada	220	130	-40.9	2	6
Netherlands	80	110	37.5	2	3
Norway	80	60	-25.0	2	6
Total	71.2	50.5	-29.1	11	37
OECD	72.1	51.3	-28.8	10	31
W. Europe	14.6	10.4	-28.8	7	17

Source: SIPRI (2001)

Military R&D (PPP dollars bn):

	1991	2000	%change
France	6.5	3.1	-52.3
Germany	2	1.3	-35.0
Italy	0.7	0.1	-85.7
Netherlands	0.1	0.1	0.0
Norway	0.1	0.1	0.0
Spain	0.6	1.3	116.7
Sweden	0.7	0.1	-85.7
UK	4.4	3.7	-15.9
Total EU	14.9	9.7	-34.9
USA	49.7	42.6	-14.3
EU and USA	64.6	52.3	-19.0

SIPRI (2003)

More recent data provided by SIPRI shows military R&D in billion ppp dollars between 1991 and 2000. This shows that not only does US expenditure on military R&D continue to dwarf EU expenditure, but that over the decade EU expenditure declined by nearly 35%, while US expenditure fell by just over 14%.

3.5 Trade

The arms trade, measured in 1999 dollars, WMEAT (2002) dropped from its all time peak of $86.7 billion in 1987 and the 1994 trough of $43.5 billion, rising to $58.4bn in 1997 and dropping back to $51.6 in 1999 as the Asian crisis deterred the big buyers in the region.

Table 3
Top 15 Arms Importers and Exporters 1997-1999
Billions of Current Dollars

Importers		Exporters	
Saudi	27.5	US	91.5
Taiwan	17.4	UK	15.7
Japan	7.9	France	15.7
UK	6.6	Russia	7.9

Turkey	6.2	Germany	4.5
Israel	5.8	Sweden	2.9
S Korea	5.3	China	2
US	5.1	Canada	1.6
Australia	4	Israel	1.6
UAE	3.7	Ukraine	1.5
Greece	3.7	Italy	1.3
Egypt	3.2	Australia	1.1
Kuwait	3.2	Netherlands	1.1
Germany	2.7	Belarus	0.9
Netherlands	2.3	Spain	0.8

This fall in demand led to a large increase in competition, particularly in export markets. The extreme case was the 1993 sale of 436 Leclerc tanks to the United Arab Emirates by Giat of France, who managed to lose nearly 1.2bn euro on a 3.13bn euro contract, though the loss was exacerbated by some unfortunate currency hedging. The profitability of arms export contracts has also been the subject of policy concern in the UK, see Chalmers et al. (2002). The increase in competition was associated with an increase in concentration discussed in the next section.

Traditionally, because the state, which had strong national preferences, was the customer, major countries largely relied on their domestic defence industries. Unlike most manufacturing industries, which went multinational, the arms industry remained national. Smaller countries which could not afford the large fixed costs imported major weapons systems (Dunne, 1995). With the fall in demand, the ability of even the major countries to maintain a domestic defence industrial base was called into question, making them more willing to import. As a result domestic and foreign weapons came to be regarded as closer substitutes than in the past.

Table 4

Numbers of weapons delivered

	1988-90	1997-99
Land	31,761	14506
Sea	424	364
Air	5537	2459
Missiles	23,165	7667
Total	60887	24996
Value	70743	51753
Price	1.161874	2.070451

The minor powers traditionally provided the bulk of their equipment from national defence industries. Again this seems no longer feasible. The problems are well brought out in the introduction to the UK government's Defence Industrial Policy

> "In recent years defence has experienced profound change. The global political context has altered dramatically, and the nature of military operations and of equipment has similarly been transformed. A manpower intensive, platform-heavy and predictable doctrine has been replaced by the requirement for sophisticated, rapid and precise military solutions. The UK Government's response to the new strategic environment, and the drive for efficiency, culminated in the Strategic Defence Review and in particular the Smart Acquisition reforms. These have placed new demands on a defence industry already changing globally in response to new market conditions, and a new emphasis on closer co-operation and openness in our relationship with industry. The ongoing consolidation of the defence and aerospace industries, dominated by a few giant companies and a multiplicity of international joint ventures, has major implications both for the future of an exclusively "national" defence industry and for competition. "(Ministry of Defence Policy Paper No. 5, October 2002):

The UK has taken a much more free-market approach to defence procurement than the other minor powers, believing that it will benefit from a more efficient globalised industry. However, the more extensive arms trade that would be associated with a more globalised arms industry raises a set of issues that we have discussed elsewhere, Garcia-Alonso (1999, 2000) Garcia-Alonso & Levine (2002), Garcia-Alonso & Hartley (2000), Levine Sen & Smith (1994), Levine and Smith (1995, 1997a,b, 2000a,b) Levine Mouzakis and Smith (2000).

3.6 Industrial Structure

Governments also had to decide whether to allow mergers and acquisitions which would reduce competition and in particular whether to allow mergers and acquisitions which involved foreign partners. The most striking change in industrial policy was in the US. In 1993 a merger wave was stimulated by the `last supper' when the Pentagon Deputy Secretary Perry told a dinner of defence industry executives that they were expected to start merging. It ended when the Pentagon decided it had gone far enough and blocked the merger of Lockheed Martin with Northrop Grumman in early 1997 (Markusen and Costigan, 1999). This left the four major contractors in Table 5, with more recently, Northrop Grumman taking over aerospace and information technology company TRW to make it the third largest US arms producer after Lockheed Martin and Boeing (SIPRI, 2002).

Table 5: US Defence Mergers

Companies in 1993		Companies after 1996
Boeing		
Rockwell		BOEING
McDonnel Douglas	1997	
Lockheed		
Martin Marietta	1994	
GE Aerospace	1992/3	LOCKHEED MARTIN
Loral		
General Dynamics	1992/3	
GM Hughes	1998	
E Systems	1995	RAYTHEON
Raytheon		
Texas Instruments	1997	
Northrop		
Westinghouse	1996	NORTHROP GRUMMAN
Grumman	1994	
TRW	2002	

In Europe the process was more complicated, since restructuring necessarily involved cross-border mergers, which raised political issues. The major players in Europe also had quite different ownership structures, including a substantial degree of state ownership in France. Both factors made a financially driven merger boom of the US type more difficult. Nonetheless, there was an increase in concentration, culminating in the acquisition of GEC defence interests by BAE Systems in the UK and the formation of the EADS (European Aeronautics, Defence and Space) company from DASA (a subsidiary of Daimler) of Germany, Aerospatiale-Matra of France and CASA of Spain. In 2002 the two largest military vehicle producers merged into one, Alvis.

Using the data on the hundred largest arms producing firms collected by SIPRI, Table 6 shows that in 1990 the 5 largest firms accounted for 22% of the global market.

Compared with other high technology markets, this is a very small percentage, close to the Sutton (1998) lower bound for the C5, which is 20%[7]. It seems likely that major weapons systems would be a very concentrated market like civil airliners or pharmaceuticals, had not national governments inhibited the growth of multinational firms in order to maintain national defence industrial bases. With the fall in demand and the relaxation of government restrictions on concentration the C5 had doubled to 42% by 2000, though this is still low relative to other industries. The other concentration ratios show similar changes. It is also interesting to note that in terms of total sales, including civil products, concentration was higher in 1990 than arms sales and rose considerably less, leaving arms and total sales measures very similar in 2000. This may well reflect an increasing specialisation on defence sales by the major players.

Table 5: Concentration Ratios

% of combined total of Top 100

	Arms sales			Total sales		
	1990	1995	2000	1990	1995	2000
5 largest	22	28	42	33	34	40
10largest	37	42	58	51	53	57
15 largest	48	53	66	61	65	68
20 largest	57	61	72	69	73	76

Source: SIPRI (2002)

The degree of change in the international arms industry is further illustrated in Table 7, which presents the arms sales data for companies that were in the top 10 in 1990 and or 2000. The change in the companies making up the top ten arms producers (in terms of arms sales) in 1990 and 2000, reflects the mergers that took place, in the industry. The degree of concentration that took place is also clear. The share of the top ten in the top 100 increased from 38% to 56%, with the average size of a top 100

[7] Sutton (1998) provided a lower bound on the concentration that one might observe in the market. It is based on the assumption that any observed industry is built up from a range of sub-markets. In the international arms industry the sub-markets are defined by the various types of weapons from particular countries. He shows that certain basic principles, (e.g. firms make enough profits to cover their fixed costs and no viable sub-market will be left unexploited) provide restrictions on the set of Nash equilibria, and these together with fairly weak conditions on whether incumbents or entrants will enter a new sub-market opportunity provide a lower bound on concentration. See Dunne et al (2002).

company declining from $187 billion to $158 billion, while the top 3 companies almost doubled their arms sales.

Table 7

			Rank		Arms Expenditure		
			1990	2000	1990	2000	% Change
1	McDonnell Douglas	USA	1	-	9,890		-100.0
2	BAE Systems	UK	2	3	8,710	14,400	65.3
3	General Dynamics	USA	3	6	8,300	6,520	-21.4
4	Lockheed Martin	USA	4	1	7,500	18,610	148.1
5	General Motors	USA	5	49	7,380	540	-92.7
6	General Electric	USA	6	20	6,450	1,600	-75.2
7	Raytheon	USA	7	4	5,500	10,100	83.6
8	Thales	Fr	8	8	5,252	5,160	-1.8
9	Boeing	USA	9	2	5,100	16,900	231.4
10	Northrop Grummann	USA	10	5	4,930	6,660	35.1
11	United Technologies	USA	13	11	4,100	2,880	-29.8
12	Litton	USA	19	9	3,000	3,950	31.7
13	TRW	USA	20	10	2,980	3,370	13.1

4. Procurement technology and Industrial Structure

In an attempt to capture the characteristics of the new security situation, we develop a model with military strength a generalised Dixit-Stiglitz CES function of quality-adjusted numbers of each variety, with domestic and imported varieties weighted differently. This captures the four margins discussed above: quality, quantity, no of varieties (different types of weapons) and origin of the weapons. The generalisation allows for a taste for variety parameter distinct from the parameter that measures substitution between varieties. The cost of producing each variety has a fixed cost, an R&D cost of developing quality and a marginal cost. In practice only a sub-set of countries, the main powers, produce major weapons systems, the remainder import from the producers. The decision to establish an arms industry is examined as an irreversible investment problem in Levine and Smith (2000a), here we treat it as exogenous. Thus the number of varieties and, since we assume each variety is produced by a single firm, the number of firms in the global industry is determined by the procurement decisions of the arms producing countries. They do this at the first stage of the game. At the second stage the firms compete in a Bertrand game on the international market to determine the international price for each variety, which may be different from the domestic procurement price. At the third stage countries import and export.

Producers are regarded as large powers whose requirement for military strength is regarded as insurance against a variety of unspecified threats and military expenditure is exogenous. Non-producers are regarded as pairs of minor powers preparing for a specific confrontation with each other, with either a ratio or difference conflict success function and a budget constraint in which output can be spent on military strength or consumption. The form of the conflict success function is crucial to the analysis. With the ratio form the military expenditure of non-producers is independent of the number and quality of the varieties of weapons. With the difference form, as military expenditure falls and welfare increases the number and quality of weapons decreases, e.g. through export controls.

We compare non-cooperative and cooperative outcomes between producers. From the point of view of the producers the non-cooperative outcome is inefficient for two reasons. First, variety is a positive externality and governments acting independently would choose to support too few firms and under supply variety in total. In the absence of an external market this would lead to *less firms* in the non-cooperative equilibrium than with cooperation. Second, competition for the external market can introduce inefficiency. There are two effects of cooperation on firm numbers, which operate in opposite directions. First, ignore quality and focus on variety. The fact variety is exported benefits the importers, but not the exporter unless it results in an increase in demand. Whether this happens, depends on the form of the contest success function. For the ratio form, assumed in the simulations reported, military expenditure of non-producing importers is constant, as a proportion of income, and then there are no benefits to exporters from increasing the variety offered to non-producers. As the external market of non-producers increases in relative size, producers therefore support fewer firms allowing each firm to spread its fixed costs over a larger market share. Under non-cooperation, however, this reduction in firm number is too little, compared with cooperation, because governments acting independently only care about competition between domestic firms. Thus in the absence of quality considerations, the existence of an external market results in the number of supported firms being *greater* under non-cooperation compared with cooperation.

Introducing quality, a further inefficiency arises from competition, which encourages too much investment in quality relative to a cooperative outcome. When governments raise quality unilaterally this increases market share. In equilibrium however the benefit to competitiveness disappears and countries are left with too much quality and *too few* large firms under non-cooperation compared to that chosen cooperatively. To summarize: the presence of an external market tends to reduce firm number (i.e. raise concentration) and encourage investment in quality. The latter effect results in two few firms in the non-cooperative equilibrium compared with cooperation; but, in the absence of investment in quality there would be too many firms compared with cooperation.

In the simulations reported we confine ourselves to the ratio form of the conflict success function. We examine a symmetric equilibrium of three countries (e.g., in an EU context, the UK, France and Germany). Parameter values are calibrated so that the non-cooperative equilibrium reproduces stylized facts for firm numbers, military expenditure, R&D as a proportion of output and subsidies given to the defence industry. We focus on the effect of changing three crucial parameters; β which measures the cost of achieving a particular quality of weapon, w lying between ½ and 1 measuring the bias for domestic production in the procurement decision and Φ, the ratio of military expenditure by non-producing country to tottal world military expenditure.

In our first experiment we examine the effect of more process innovation and escalating fixed costs associated with R&D investment by allowing the parameter β to fall. In figures 1 and 3 we see that with a high value β, R&D as a proportion to total output is low, and comparing the non-cooperative equilibrium with the optimal cooperative arrangement the number of firms is too high. As β falls, R&D investments rises until at β =1.5 we can reproduce data on R&D as a proportion of output which suggests figures of 20-25\% (see Dunne et al, 2002). The firm number falls substantially seeing a total of around 160 at the low R&D end to around 100 at β =1.5, at the latter high-investment end an absence of cooperation sees an insufficient number of firms and an excessive production of quality. The beggar-thy-neighbour aspect of quality in the external market drives this result. When countries order high-tech, high quality specifications for domestic procurement, acting independently they improve the competitiveness of their exports to the external market. In a Nash equilibrium however these gains are wiped out: R&D expenditure is high but there is no improvement in competitiveness. A subsidy (seen in figure 2 where the procurement price exceeds the world price is then required and figure 4 shows that the gains from cooperation between producer countries (to those countries) rises substantially with more process innovation.

In our second experiment we set β =1.5 and allow the domestic procurement bias parameter, w to increase from w=0.5 to w=1 at which point producing countries are self-sufficient, and only exporting to non-producers. In figure 5 the number of firms per country in the non-cooperative equilibrium first falls and then rises with w. As countries become more self-sufficient they internalize the benefits of variety and choose to support more domestic firms. On the other hand they also internalize the benefits of investment into quality, raising fixed costs and tending to reduce the number of firms. The net effect is the U-curve. Under cooperation firm number is independent of w. In Figure 5, for higher values of w, both firm number and quality increases in the noncooperative equilibrium and consequently, from figure 6 the subsidy (procurement price minus the world price) also increases. There are two affects at work here: taste for variety tends to encourage subsidy whilst the external market effect encourages the opposite (a tax on export profits). With our parameter values in the non-cooperative equilibrium the former effect dominates for higher values of w.

Figure 7 shows total output per firm in the non-cooperative equilibrium broken down into exports to non-producers and producers and domestic procurement. As w increases exports to producers fall and initially output is diverted to domestic procurement. With the increase in the number of firms, the total size of each firm falls and all three components eventually fall for higher values of w. The utility loss to producers from failing to cooperative are shown in figure 8. Considering the welfare of producers only, in the absence of cooperation are `too few' firms and they produce `too much quality'.

In our final experiment we fix the preference parameter at w=0.5, so there is no domestic bias in the procurement decision, and we allow the proportion of world demand from non-producers Φ to increase from Φ =0.5 towards unity. Figures 9 to 12 show the numerical results. Figure 9 shows that the subsequent fall in the firm number under both non-cooperation and cooperation as Φ rises as before there are too few firms and too much quality in the absence of cooperation. From figure 10 these changes in industry structure are brought about by initially a subsidy under non-cooperative giving way to a tax at higher values of Φ. The optimal (cooperative) procurement price for the producers, by contrast, involves a substantial tax throughout the full range of Φ.

A falling number of firms as Φ rises is associated with a rise in the size of each firm. Figure 11 shows this happening and a switch of output from domestic procurement and internal trade to the external market. Figure 12 shows that the gains to cooperation between producers rise substantially as the external market becomes more important. This is largely the result of excessive investment into quality but a close examination of figure 9 reveals that the difference in firm number between the cooperative and non-cooperative outcome also rises contributing to this welfare deficiency.

5. Asymmetric Warfare

One feature of the Lanchester square law formulation is that numbers matter more than technology. Suppose that side A replaces, say 1000 riflemen by 200 machine gunners, who are each 25 times as effective, i.e. now $q_A = 25q_B$. But five enemy riflemen would each be targeting each machine gunner, who would on average last one fifth as long as the rifleman he replaced, so is only five times as effective rather than 25 times. Bellany (2002) discusses this example in the context of asymmetric warfare, which he interprets as a significant qualitative asymmetry in the technical level of sophistication of the armaments employed by each side. He uses the Boer War as an example, where although the British eventually won, they had great difficulty in turning their technical superiority in weapons, including machine guns, into military advantage. Boer leaders, unlike World War I commanders, did not think it sensible to order their troops forward to be mown down by the opponent's machine guns, so the battles were no longer described by this particular law.

One could then imagine asymmetric warfare as described by a stage game in which the incumbent has to optimise, not knowing what tactics its opponents would adopt, i.e. which value of λ it would choose. The attacker then chooses the tactics, λ, which would put the incumbent at a disadvantage. The US might choose a general-purpose technology of combat, aerial bombing with $\lambda = 1/2$, but this can be indecisive and can be thwarted by specific optimised technologies in particular circumstances. For instance, the opponents can choose to create circumstances that require, for instance, the US to engage in urban fighting if it wishes to prevail, where $\lambda = 0$ and technology is relatively less effective. If the opponent can entrap the US forces into a quagmire, a fear since Vietnam, $\lambda = 1$, and the US forces may self-destruct.

Hirschliefer argues that the role of the economist is not to replace the technical experts in the micro-technology of conflict, but to address the macro-technology of conflict, making use of such familiar concepts as increasing and decreasing returns, economies of scale and scope, and factor substitution. In doing this the CSF function is treated as basic, rather than being derived from specific scenarios as Lanchester and Intriligator do. In addition, as Hirschliefer (2000, p774-5) recognises the CSF describes the mechanics of attrition, grinding your opponent down; but a lot of warfare is about manoeuvre, using your forces to catch your opponent at a disadvantage a fact emphasised by Luttwak (1987) who he cites. But Luttwak explicitly rejects the production function approach "when it comes to military power, the relationship between material inputs and desired outputs is not proportional; it is in fact very loose, because the making of military strength is dominated by nonmaterial, quite intangible human factors, from the quality of military strategy to the fighting morale of individual servicemen.". It is these intangibles that the CSF lacks

In attempting to develop this framework of analysis to take account of modern warfare, it is these intangibles that are central. In the case of asymmetric warfare the opponent attacks you in the way that you did not prepare for. In this sense, the CSF can never be exogenously given, but it is chosen as a result of the combatants strategic choices. Ex ante, one side may not know which CSF the opponent will choose. The rest of this section develops a model that takes into account the characteristics of asymmetric warfare.

We can think of asymmetric warfare as involving either different technologies, types of weapon, or different tactics, ways of fighting; in practice it will often involve both but we will treat them as a single dimension. We will treat the contestants as also being asymmetric, there is an incumbent and a challenger: government facing potential rebels, dominant power facing potential revisionist power. Such conflicts are often characterised by periods of armed peace interspersed by outright war as one or other side of both side decide to attack. Regard them as fighting over a prize, e.g. the revenue derived from a natural resource such as oil, diamonds or drugs. Each side invests effort in preparing for conflict and chooses its tactics (or technology) and its military strategy: attack or defend. In the first period the incumbent makes decisions on effort and tactics; in the second period the challenger makes decisions about effort and tactics, conditional on those of the incumbent; in the third period they simultaneously decide to attack or defend and receive their payoffs.

The asymmetry arises because one side can gain an advantage by choosing to fight in a way that the opponent is not prepared for, i.e. choosing tactics very different from the enemy. We represent choice of tactics as choice of a point along a zero-one interval. For instance, before World War II, French tactics were largely defensive based on the Maginot line, which the Germans outflanked with a Blitzkreig attack in 1940 defeating superior British and French forces. In the late 19th century, the machine gun was a major technological advance, which gave the British a great advantage in Colonial Wars; but the Boers were largely able to neutralise this advantage through their tactics and although the British did eventually win it was a longer and more expensive war than they expected .

In the traditional arms race and conflict literature (Siqueira (2002) offers a recent example within the conflict literature) the "technology of conflict" is seen as a unidimensional variable. A higher amount of effort, translated into more or more advanced weapons, is the only technological decision conflicting parties take. In reality, the world is not so simple. Technological decisions are more likely to be multidimensional. Not only will effort and/or quality be chosen, but the type of weaponry and the training the opposing forces acquire will need to be chosen. This means that there is much greater scope for a potential asymmetry of technologies across potential combatants.

Such a situation is most likely to arise when the conflicting powers are themselves asymmetric in nature. The most likely scenario is an incumbent power with a dominance in available resources, but committed to a certain type of technology, and a smaller challenger, with limited resources but more flexibility in choice of technology. Most incumbent powers one could think of tend to have military capabilities whose characteristics are very similar and when similar sized powers engage in conflicts or arms escalation they do so with those very similar technologies. The Cold War, for instance, was mainly a vertical arms race, with similar types of technology on both sides and effort/quality the main strategic variable (Walker, 1994). Having invested considerable resources in a particular conflict technology and having developed the industry to produce it (and export it), incumbent countries would find it difficult to change.

A second possible explanation of the persistence of conflict technologies used by incumbent powers, is that strategists consider it the most suitable means by which to fight the "average threat" in the Post Cold War era. An era in which potential conflicts are not easily foreseen. Challengers do not have this problem, their constrained resources and small share of existing wealth may actually encourage them to find new ways of fighting. Such novelty could become an advantage in certain types of conflicts and compensate to some extent for their lack of resources. This suggests that it may actually be the very availability of resources that established powers enjoy, that encourage for contestants to design new and potentially dangerous conflict technologies. One implication of this is that limiting the effort that incumbents put into preparing for conflict may be one means of decreasing the probability of a damaging attack by a contestant group.

The above situation is not too dissimilar from the developments in competitive behaviour in the computer industry During the 1990's IBM was clearly the main player in the computing industry having for long a long period had a particular way of doing business and a well established customer base. In a few years, however, the industry changed dramatically, as "instead of competing directly with the established leader, entrants opened up new market segments". Later, some of these entrants became challengers to IBM's power and those that prevailed where the ones who won the standardization war, namely Microsoft and Intel. (Bresnahan and Greenstein, 1999; Sutton 1998). This final outcome was not in any way certain ex-ante, a further characteristic shared with military conflict.

It is possible to take the traditional conflict model and to develop it to capture some of the components of asymmetric warfare. In such models the probabilities of winning conflicts are generally increasing functions of ones own effort and a decreasing functions of the opponent's effort. To make this bi-dimensional and so allow for asymmetric conflict, we introduce an additional parameter in the probability function, to represent the degree of horizontal technological differentiation from the incumbent power.

The probability of winning a conflict, the Contest Success Function, depends on which party attacks and which one needs to defend itself. If only one party attacks (the other acting defensively) the attacking party will have an advantage whenever the technology used for the attack differs from the technology that the defending party has. For example if one party decides on a missile attack, they will have an advantage (both sides making similar efforts) if the defensive party does not have advanced missile technology, as this means they are unlikely to have antimissile systems. Similarly with biological warfare, the attacker will have an advantage if the defender does not have biological weapon capability, as they are unlikely to have specific defences against the agents. Asymmetric technology can give a contestant an advantage if they are on the offensive but, if they are on the defensive, technology differentiation can become a liability.

Referring to the incumbent power and challengers' interaction is represented by the following multiple stage game:

Stage 1: The incumbent chooses its effort. The challenger's effort is considered exogenous and is based on them using all their available funds, while the incumbent allocates the country's budget across a range of expenditures and so has more flexibility when it comes to choosing their effort.

Stage 2: The challenger chooses the type of technology to acquire, while the technology used by the incumbent is considered to be exogenous. Technological differentiation across the parties is represented by a variable which increases as technological differences between the challenger and the incumbent widens and takes the value zero if they are exactly the same[8]. Technology types could range across atomic devices, biological warfare, conventional weapons, internet warfare, etc…

Stage 3: Incumbent and challenger decide simultaneously whether to adopt an attacking or defensive strategy. The probabilities of winning the war will be determined by who attacks and who defends. If only one of the two parties adopts the attack strategy, they will have the advantage if their technology differs from that of the defending party. If both parties adopt an attack strategy, the technological

---

[8] Even though they are the same technologically, they may be of different quality, a feature that will be captured by the effort variable.

differences will cancel each other out and success probabilities will be solely based on effort levels. If nobody attacks, the parties have an exogenously given share of resources, which could also represent a share of resources agreed by means of peaceful negotiation. We can find the Subgame Perfect Equilibrium of this game using backwards induction.

A few assumptions are needed to solve the model. First, we assume that some of the resources are destroyed through conflict, with levels of destruction being higher in a conflict in which both parties adopt an attack strategy (in what follows we will refer to this as mutual attack). Second, we assume that the incumbent's share of resources if no conflict erupts is greater than the share it would expect to get through conflict, with the opposite being assumed for the challenger.

Solving the model under these assumptions gives the result that a mutual attack strategy becomes a possibility only once we introduce technological differentiation. However, challengers will block mutual attack equilibrium by limiting technological differentiation. Given this, there are two possible candidates for the equilibrium in the last stage of the game: no conflict and a conflict in which the incumbent adopts a defensive strategy and challengers adopt an attack strategy. Through its choice of effort, the incumbent may be able to implement either of these two equilibria as the unique equilibrium in the final stage of the game. Interestingly, it may actually be "cheaper" in terms of effort for the incumbent to induce a defensive conflict, especially if the no conflict shares of resources are balanced in favour of the incumbent. If the incumbent targets a defensive conflict, when the challenger has the option of technological differentiation from the incumbent, then the outcome is a lower level of effort by the incumbent. However, if the incumbent wants to prevent conflict, when the challenger has the option of differentiation, the level of effort required will actually be higher. This leads to the conclusion that the incumbent is less likely to want to prevent conflict when technological differentiation becomes a possibility.

6. Conclusions

This paper has provided an analysis of the economics of the Revolution in Military Affairs through a review of developments in the post Cold War period……

Drawing on comparisons between the putative New Economy of defence, the RMA and asymmetric warfare, and the putative New Economy in Civilian life, where changes in technology transformed production and distribution making dominant incumbents, like IBM, vulnerable to attack by initially small competitors, like Intel and Microsoft, who followed different strategies. In the new economy literature it is common to distinguish incremental and disruptive technological change. Under the former competition proceeds down well established product and process technological trajectories. Under the latter the industry and market is completely transformed. We will make a similar distinction with the early part of the paper emphasising incremental changes in military technology, the latter disruptive change.

Using a rational actor model that assumes that agents, states or non-state actors, acquire armed forces because of their utility in combat. The decision maker perceives potential threats, assesses the military capabilities required to counter the threat, determines the force structure that will provide those military capabilities and subject to a budget constraint determines the optimal force structure.

This model captures important aspects of military planning for nations with recent combat experience or hostile neighbours, US, UK, France, Russia, Greece, Turkey, etc. It probably does not capture the experience of those nations who do not expect their armed forces to fight. Defence budgets in such countries have different functions.

Section 2 provides some background on the current military environment.
Section 3 examines the economic dimensions of that environment.
Section 4 provides a model of the interaction of procurement, technology and market structure.
Section 5 discusses asymmetric warfare.

Section 6 models managing asymmetric conflict.

References

Anderton, Charles H (2003) Economic Theorising of Conflict: Historical Contributions, Future Possibilities. *Defence and Peace Economics*, Vol 14, 3, June, 209-222.

Anderton, Charles H (1992) Towards a mathematical theory of the offensive/defensive balance, *International Studies Quarterly*, 36, 75-100.

Anderton, Charles H (2000) An insecure economy under ratio and logistic conflict technologies, *Journal of Conflict Resolution*, 44 (6), 823-838.

Bellany, I (2002) Fighting Asymmetric Wars: An application of Lanchester's Square Law to Modern Warfare, RUSI Journal, 147,5 October 2002, p72-76.

Bresnahan and Greenstein (1999) Technological Competition and the Structure of the Computer Industry, *Journal of Industrial Economics*, vol. XLVII, no 1, 1-40.

Chalmers M, NV Davies, K Hartley and C Wilkinson (2002) The Economic Costs and Benefits of UK Defence Exports, *Fiscal Studies* 23, 3, 343-367.

Collier, Paul (2000) Rebellion as a quasi-criminal activity, *Journal of Conflict Resolution*, 44 (6), 839-853.

Collier, Paul and Anke Hoeffler (2002) Military Expenditure: Threats, Aid and Arms Races, on http://econ.worldbank.org/programs/conflict

Coulomb, Fanny (1998) Adam Smith: A Defence Economist, *Defence and Peace Economics*, Vol 9, 3, pp 299-316.

Dixit A (2002) Lawlessness and Economics: Alternative Modes of Economic Governance, Gorman Lectures, University College, London.

Dunne, J. P. (1995) The Defence Industrial Base. Chapter 14 in Keith Hartley and Todd Sandler (eds) (1995) *Handbook in Defense Economics*, Elsevier, pp 592-623.

Dunne, J.P., Garcia-Alonso, M., Levine, P. and Smith R. (2002) Concentration in the International Arms Industry. Paper presented at the ECAAR Panel Session, *American Economics Association/ASSA Annual Meetings*, Atlanta January 2002. Available at: http://carecon.org.uk/Armsproduction/.

Dunne, J.P. and S. Perlo-Freeman (2003) The Demand for Military Spending in Developing Countries. *International Review of Applied Economics*, Vol. 17, no. 1, pp. 23-48.

Freedman, Lawrence (ed) (1994) *War*. Oxford Readers, Oxford University Press.

García-Alonso, M.C. and P. Levine (2002) Domestic Procurement, Subsidies and the Arms Trade. Chapter 7 in Brauer, J. and Dunne, P. (eds) (2002) *Arming the South: The Economics of Military Expenditures, Arms Production and Trade in Developing Countries.* Palgrave

García-Alonso, M.C. (1999) Price Competition in a Model of Arms Trade, *Defence and Peace Economics* 10, 3, 273-303

García-Alonso, M.C. (2000). The Role of Technology Security in a Model of Horizontal Differentiation, *International Journal of Industrial Economics* 18, 5, 747-773.

García-Alonso, M.C. and K.Hartley (2000). Export Controls, Market Structure and International Coordination, Discussion Paper at the University of Kent, *Defence and Peace Economics,* Vol 11, Issue 5, September.

Gershenson, Dimitry & Herschell I. Grossman (2000) Civil Conflict: Ended or Never ending, *Journal of Conflict Resolution*, 44 (6), 808-822.

Gleditsch, N.P. P. Wallensteen, M Erikson, M Sollenberg and H Strand (2002) Armed Conflict 1946-2001: A new Dataset, *Journal of Peace Research*, 39,5, p615-637.

Harris, Geoff (1999) *Recovery from Armed Conflict in Developing Countries*. Routledge.

Hirshleifer Jack (2000) The Macrotechnology of Conflict, *Journal of Conflict Resolution,* 44 (6) p773-792.

Intrilligator Michael (1976)

Kaldor, Mary (1999) *New and Old Wars: Organised Violence in a Global Era*. Polity Press

Kirkpatrick, David (2000) Revolutions in Military Technology and their Consequences, Inaugural Lecture, Defence Engineering Group, University College London.

Lanchester, Frederick William (1916) *Aircraft in Warfare; the dawn of the fourth arm*, London Constable & Co.

Levine, P., Sen, S. and R. Smith (1994) A Model of the International Arms Market, *Defence and Peace Economics*, 5, 1-18.

Levine, P. and R. Smith (1995) The Arms Trade and Arms Control, *Economic Journal*, 105, 471-484.

Levine, P. and Smith, R. (1997a). Regional Arms Races and the Arms Trade, *Journal of Economic Dynamics and Control*, 21, 631-654.

Levine, P. and Smith, R. (1997b). The Arms Trade, *Economic Policy*, October, 337-370.

Levine, P. F Mouzakis and R.P. Smith (2000). Arms Export Controls and Emerging Domestic Producers, *Defence and Peace Economics*, 11, 505-531.

Levine, P. and R.P. Smith (2000a) The Arms Trade Game: from Laissez-faire to a Common Defence Policy, *Oxford Economic Papers*, 52, 357-380.

Levine, P. and R.P. Smith (2000b) Arms Export Controls and Proliferation, *Journal of Conflict Resolution*, 44, 885-895.

Lorel, Mark, Julia Lowell, Michael Kennedy & P Levaus (2000) *Cheaper, Faster, Better; Commercial Approaches to Weapons acquisition*, Rand.

Luttwak, Edward N (1987) *Strategy: The logic of War and Peace*, Harvard University Press.

Markusen, Ann R. and Costigan Sean C. (eds) (1999) *Arming the Future*. Council on Foreign Relations: New York.

Mathews, Ron and John Treddenick eds (2001) *Managing the Revolution in Military Affairs*, Palgrave.

McGuire M and Olson M (1996) The economics of autocracy and majority rule: the invisible hand and the use of force, *Journal of Economic Literature*, 36 (1) 72-96.

Newman N.J. (2000) *Asymmetric threats to British Military Intervention Operations*, Whitehall Paper 49, Royal United Services Institute.

Parker, Geoffrey (1988) *The Military Revolution: Military innovation and the Rise of the West, 1500-1800*. Cambridge University Press.

Rider, Robert, (2002) Plunder or Trade, *Defence and Peace Economics* 13 (3) 199-214.

Rotte, Ralph and Christoph M. Schmidt (2003) On the Production of Victory: Empirical Determinants of Battlefield Success in Modern War, *Defence and Peace Economics*, 14,3, 175-193.

Sambanis, Nicholas (2002) A review of recent advances and future directions in the quantitative literature on Civil War, *Defence and Peace Economics* 13 (3) 215-244.

Sandler, Todd (2000) Economic Analysis of Conflict, *Journal of Conflict Resolution*, 44 (6), 723-729.

Siqueira, K (2002) Conflict and third party intervention, mimeo, Clarkson University, NY.

SIPRI (various years) *SIPRI Yearbook.* SIPRI and Oxford University Press.

Stauvermann, Peter (2002) Why is there so much peace? *Defence and Peace Economics* 13 (1) 6-76.

Stone, Richard (1988) When Will the War End? *Cambridge Journal of Economics*, Vol 12, 2, pp193-210.

Sutton, John (2001) *Technology and Market Structure: Theory and Market History*. The MIT Press.

Thompson, Earl (1979)

Thompson, Earl (1974)

Walker, Martin (1994) *The Cold War*. Vintage: London.

WMEAT (2002) *World Military Expenditures and Arms Tr*ade. US State Department.