The Evolution of the International Arms Industry

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Abstract

This paper considers the changes that have taken place in the international arms market over the last decade and the effect that it has had on the arms industry. Using arms company data collected by SIPRI we provide a preliminary quantitative analysis of the changes in the structure of the market and the degree of concentration.

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1 Introduction

The end of the Cold War led to a large drop in military expenditures and the demand for arms. This paper examines how the firms that produced those arms responded and how the Western defence industry evolved. The arms industry is somewhat unusual in that its customers, governments, can shape the structure of supply by their procurement policies and regularly use those policies to try to create the type of Defence Industrial Base that will best provide them with the type of arms they think that they will need in the future. Government defence industrial policy thus sets a perimeter within which arms firms can set their corporate strategy. It is a loose perimeter in that firms can lobby to change policy and they can go off and find other governments to sell to (subject to arms export control policies, another part of the perimeter); but it is a perimeter, a constraint on corporate strategies. Thus in making their strategic choices, companies were making judgements about what governments would accept, or could be made to accept by the methods of persuasion arms firms usually employ.

Below we examine the policy context; review the options available to companies; consider various ways of explaining changes in concentration; measure the change in concentration in the industry; discuss some econometric issues and present some econometric evidence on the growth of arms sales by firms. The empirical analysis is largely based on the annual estimates SIPRI makes of the 100 largest arms producing companies. The final section has some concluding comments.

2 Policy Context

World military expenditures and arms exports peaked in the middle 1980s, fell gradually at first with improving East-West relations, then fell rapidly with the disintegration of the Soviet Union. BVC (2000), previously ACDA, estimates that world military expenditure fell at about 6% per annum in real terms over the decade 1987-1997, -7.3% a year in the developed world and -0.9% a year in the developing world. The most dramatic fall was in the former Soviet Union. The arms trade dropped by a half between the 1987 all time high of $81.5 billion and the 1994 trough of $42.2 bn (in 1997 prices), rising to $54.6bn in 1997. The Asian crisis of 1997 subsequently hit arms sales, since this was an area where demand had been strong. Procurement of weapons also fell sharply. SIPRI (2000) estimate 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. Production for the military is not homogeneous. It consists of a whole range of products, from small arms to large complicated weapon systems as well as material that is not directly military. Here we will emphasise major weapons systems. These have particular characteristics that have over the years have led to particular corporate structures. They involve high fixed R&D costs financed by the governments and fairly short production runs with steep learning curves. Production is concentrated in relatively few states, in contrast to small arms production, which is relatively standard and widely dispersed (Dunne, 1995).

In addition, many of the components that go into the major weapons systems are commercial 'off-the-shelf' (COTS) products, produced by manufacturers would not see themselves as part of the arms industry. Indeed, the use of standard commercial components is an increasing feature of the industry.

The high fixed R&D costs and the steep learning curves, with costs falling sharply with each further unit produced, mean that major weapons producers can gain economies of scale and that their minimum efficient scale is large relative to the size of the market[1]. This means that, on the one hand, governments have been concerned that the drop in demand following the Cold War would drive firms below their minimum efficient scale, but. On the other hand competition helps keep down prices and to stimulates innovation by firms. This tension between the benefits of scale and the benefits of competition has been the central defence industrial policy dilemma for the last 40 years. A discussion of the structure at the end of the Cold War can be found in Smith (1990).

The end of the Cold War produced not just a quantitative change in the amount of weapons required, but a qualitative change in the type of weapons required. During the Cold War planning was straightforward, it was fairly clear where, how, and with whom war would be fought if it came. After the Cold War there is much less certainty, though it became apparent that the Cold War weapons that made up the bulk of the NATO inventory are unlikely to be what is required. Given the long leads times and the commitments made by government bodies, research teams and companies, there are still pressures to continue to produce these weapons systems and to find roles for them. There has, however, been a clear and important qualitative change in the nature of technology. There were two aspects to this. First, investments in military technology paid off and some, though not all, smart precision-guided weapons actually met the promises that had long been made for them. The power of these, mainly US, technologies was demonstrated in the Gulf. Second, the relative positions of military and civilian technology were reversed. From the end of World War II to the 1980s, military technology had tended to be in advance of civilian technology, but by the 1990s in many areas, particularly electronics, military technology lagged the civilian sector. This was largely because the long lead times involved

[1] Though Hartley (19??) has shown that in defence aerospace production these economies of scale do flatten off relatively quickly. The learning curve is steep but L shaped.

in military procurement meant that much of the technology was obsolete before the system came into service. Eurofighter, a 1980s design, is not even in service yet. Whereas in the past the spin-off of military technology to the civilian sector was the focus of concern and an important argument for the value of military production, now the focus is more on spinning-in civilian technology to the military. Many areas of technology which were once the preserve of the military and security services, such as cryptography, are now dominated by commercial applications. Fitting civilian technology into military applications can be difficult as the UK found in developing a new tactical radio for the army. Fortunately, when in action UK troops can supplement the heavy 1970s radios issued to them, with their personal mobile phones.

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. With the fall in demand, the ability of even the major countries to maintain a domestic defence industrial base was called into question. Governments 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. They were also in a situation where the change in the security environment made it harder to justify previous levels of support for the industry and 'competitive procurement policies aimed at value for money were introduced in a number of countries (Dunne and Macdonald, 2001).

The most striking change in industrial policy was in the US. During the Cold War industrial planning was undertaken through the Pentagon, but implicitly. 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 1: US Defence Mergers

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

3 The Corporate Options.

Faced with the reduction in demand firms had five options on a civilian-military axis: convert, diversify, divest, cooperate or concentrate. Their strategic options were constrained by governments policy towards merger and by the nature of the financial systems within which they operated. In principle, the conversion of plants producing military products into ones producing civilian products was an option, but there are very few examples of a successful conversion strategy over this period. As experience in the post-Vietnam downturn in military demand had shown, conversion is incredibly difficult: the markets and cultures are so different in the military and commercial arenas. Smith and Smith (1990) discuss the difficulties and more general issues of corporate strategy and culture in the arms industry. Diversification involves the development of new commercial activities either through the organic growth of new businesses or the acquisition of existing businesses. This is more likely to work if the firm can build synergies between the military and civil parts of the business. Probably the most impressive piece of diversification was the UK defence company Racal, building the Vodaphone mobile phone business in the late 1980s, which it then spun-off. The remaining defence components of Racal were ultimately sold to Thompson CSF of France, to form the multinational Thales company. There are far more examples of unsuccessful diversification. British Aerospace bought a construction company, a property company and a car company. There were plausible tactical justifications for each, but they did not work and BAe divested them and became more focussed as a defence company[2]. There was a widespread belief for a while that there were synergies between automobiles and aerospace, particularly defence aerospace, something on which Saab had based its advertising. Ford, General Motors and Daimler had all acquired defence arms. Ford and GM subsequently sold them and Daimler spun off DASA into the merger with Aerospatiale-Matra and CASA to form the multinational European Aeronatics, Defence and Space Company EADS.

Where competition regulations made it possible, divesting defence divisions by selling them to competitors was in many cases an attractive proposition, since they were worth more to the competitor who gained increased monopoly power. In the US General Dynamics was an early exponent of this strategy and shrank itself rapidly and profitably. In the UK, GEC sold its defence divisions to BAe in 1999 and turned itself into a purely commercial company, Marconi. Cooperation has always been common in aerospace and

[2] Feldman (2000) argues that BAe Enterprises, the venture capital arm had a potential for sucess that was never achieved because of the change in corporate strategy. Evans and Price (1999) describe that process of change.

defence companies use joint ventures, collaboration and strategic alliances to gain the benefits of scale without losing independence. Wood and Sorenson (2000) describe a number of case studies of military aerospace collaboration. One of the success stories is the longstanding links between the state-owned French aero-engine company SNECMA and GE of the US. Part of SNECMA is to be privatised, though the French government may be averse to allowing GE to acquire control. Joint ventures can be difficult to manage and companies prefer direct control, when they can get it. This drives the final strategy, concentration on the core weapons business. A group of companies have focused on defence, acquiring the defence divisions others divested, and often shedding civil activities. The concentrating companies, like BAe, have tended to diversify into other weapons systems to allow them to market a full product range rather than into civil.

Companies had realised the need to internationalise and had been acting upon it. Even prior to the present wave of restructuring companies were expanding supply chains internationally, building international joint ventures and taking strategic shares in foreign companies as an alternative to ownership. This trend has clearly accelerate with the support of governments and has led to marked changes in ownership structures. BAE Systems, formerly British Aerospace, now sells more to the US DoD than to the UK MoD and the French company Thales (formerly Thomson CSF), through acquisition of Racal, has become the second largest defence contractor in the UK (Skoens, 1998; 2000).

Both the argument in the previous section about the falling demand and rising fixed costs, and the discussion of the merger wave in this section, suggest increased concentration. Below we measure the increase in concentration using the SIPRI data on the top 100 arms companies, but before that it is useful to consider how economists explain changes in concentration.

4 Explanations of Concentration

Within industrial economics there are a number of approaches to the explanation of the size distributions of firms and the degree of concentration. This discussion follows Sutton (1998). One approach is statistical, following Gibrat's 1931 investigation of how the growth of firms is related to their size. We discuss and use this approach in section 6 and 7. This approach is criticised as being purely statistical, relying on stochastic processes, rather than economic analysis. From the 1950s the standard economic analysis used the structure, conduct performance approach. This started with from the underlying conditions of demand and supply which determined the structure of the industry as represented by, e.g. barriers to entry, product differentiation and the degree of concentration. Then it analysed how concentration influenced conduct, e.g. price setting behaviour, choice of advertising intensity etc., and finally how structure and conduct influenced performance, e.g. profitability and consumer welfare. A major criticism of this approach was that features that it took as exogenous barriers to entry, e.g. the nature of the technology were in fact endogenously determined by firms through their R&D for instance. In the case of the arms industry the barriers to entry, national preference by larger states and the large fixed costs required to produce major weapons systems are largely exogenous to the firms involved. This critique of structure, conduct, performance, led to a range of game theory models, in which in the first stage firms determined their R&D or other sunk costs and then in the second stage competed with prices, given their first stage investments. The difficulty with such game theory models is that their predictions are very sensitive to assumptions about unobservable features of the environment, e.g. exactly how entry can happen.

In various work, Sutton suggests an alternative approach based on both game theory models and statistical assumptions. His approach differs from the usual approach in that it does not try to predict a unique equilibrium for the game or the whole size distribution, but to provide 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 individual weapons and 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 possible Nash equilibria that can be maintained and these restrictions provide a lower bound to concentration. In addition, fairly weak conditions on whether incumbents or entrants will meet a new sub-market opportunity also provides a lower bound. The independent sub-markets models gives a lower bound on concentration of

$$c_k = \frac{k}{n}\left[1 - \ln(\frac{k}{n})\right]$$

where c_k is the lower bound for the k firm concentration ratio and n is the total number of firms in the sample.

In general, the bound will depend on the nature of the linkages between the sub-markets and the strategies of the firms. Two parameters play an important role in these strategies. The first is σ, which measures the degree of linkage between submarkets. This linkage could come from substitution between products, with $\sigma = 0$ implying they are not substitutes and $\sigma = 1$ that they are perfect substitutes, or it could come from economies of scope. The internationalisation of the market during the 1990s is likely to have increased σ and this will tend to increase the lower bound on concentration. In this context government policies of national preference can be seen as inhibiting economic forces that would tend to increase concentration and the increased concentration observed over the 1990s reflects adjustment towards a more natural level of concentration as government obstacles were removed. The second important parameter is β, the elasticity of fixed and sunk costs to quality, in the relationship introduced above, where fixed costs are Fu^{β} and $u \geq 1$ is a measure of product quality. From these he derives another parameter α (a function of β and σ) which is an escalation parameter: it measures how much extra sales one can make by outspending competitors on R&D. None of these parameters are directly observable, but they have implications for observables such as the R&D sales ratio and the degree of homogeneity of the industry.

Normally in highly R&D intensive industries, like defence, one would expect β to be low because the extra quality obtained per unit of R&D is high, making it profitable to invest in R&D. But this argument applies to R&D chosen by firms to give them a competitive advantage. In the arms industry R&D is chosen by governments to give them a military advantage. They may still invest even if it required a large R&D expenditure to give a small improvement in quality, because that small difference in quality could make the difference between winning and losing in combat. Within Suttons framework, a low β combined with a low σ can produce high R&D sales ratios and a low degree of concentration. If this was the case and the fall in military expenditures caused governments to reduce their degree of national preference, this would cause σ to rise and the lower bound on concentration to increase. This would match the case of digital telephone switches analysed in Sutton (1998, ch 5). In the case of switches, however, the mechanism by which concentration increased was an escalation in R&D intensity. This meant switches moved from a low α industry to a high α one driving out the weaker players who could not keep up with the escalation. While there has been some evidence that military R&D expenditures have proved resilient, there has not been obvious R&D escalation of that sort in the defence industry during the 1990s.

The increasing size of fixed costs relative to the market and learning curves both increase the lower bound on concentration, Sutton (1998 ch 7) discusses this effect with respect to turbine generators and they are clearly applicable to the defence industry in the way discussed in section 2. In addition to the exogenous R&D problem, there is another difficulty with Sutton's approach for the defence case. Mergers and acquisitions play no role in the models and in the arms market of the 1990s they are crucial, driving a lot of the concentration.

5 Theoretical Model

An alternative approach to understanding the global arms market is to develop a relatively abstract model that aims to capture a limited number of the features previously. This does require focusing the analysis and we do so by considering the procurement by global military authorities from a private military firms given a fixed budget. Rogerson (1991) discusses the incentive aspects of such procurement. We assume that the military authorities try to maximise military capability given by a CES production function

$$M = \left[\sum_{j=1}^{n} (q_j d_j)^{\alpha} \right]^{\frac{1}{\alpha}} ;\ \alpha \in [-\infty, 1] \tag{1}$$

where M is the military capability from the purchase of varieties $j = 1, 2, \cdots, n$ of quantity d_j and quality q_j. Military capability is not the same as security, which also depends on the capabilities of potential opponents. A variety may be thought of as a type of weapon produced in a particular country by a single firm. In (1) $\frac{1}{1-\alpha}$ is the elasticity of substitution between different varieties. Countries need a mix of weapons, hence the demand for variety, but different types of weapons are quite close substitutes in destructive power. Power projection, as in Kosovo or Afghanistan, can be done by ground troops, long-range bombers, attack aircraft launched from carriers, cruise missiles launched from submarines, etc. Technological and strategic change and the reduction of national preferences, which make different countries weapons closer substitutes, have tended to raise α towards unity since the end of the

Cold War. Raising α reduces the monopoly power of the firms producing the particular varieties. For this exercise, where the emphasis is on the supply side we are not modelling the determination of M. The demand for military expenditure, the arms trade and the decision to have an arms industry are discussed in Levine and Smith (2000). In military operational analysis, the probability of country k defeating country h is usually modelled as

$$p_{kh} = \frac{q_k}{q_h}\left(\frac{d_k}{d_h}\right)^{\eta}$$

where η, known as the Lanchester coefficient, depends on the type of combat. For dispersed individual duals it is unity, for battles between massed ranks, it is two. For cases where technological edge translates directly into victory, it is close to zero. Treating it as unity on average, as is done above by using $q_j d_j$ seems a sensible simplification.

The budget constraint is

$$\sum_{j=1}^{n} p_j d_j = G \tag{2}$$

For firm j, the cost of producing d_j of quality q_j is assumed to involve a fixed cost, an R&D cost of producing quality and a marginal cost:

$$C(d_j, q_j) = F + f q_j^{\beta} + c d_j \; ; \; \beta > 1 \tag{3}$$

This abstracts from learning curves which would make the marginal cost cd_j^{κ}. It follows that the profit of this firm is

$$\pi_j = (p_j - c)d_j - F - f q_j^{\beta} \tag{4}$$

The military authority's optimization problem is to choose quantity d_j and price p_j to maximize M, conditional on quality q_j, assumed to be observable, from a chosen number of firms subject to its budget constraint (2) and a participation constraint $\pi_j \geq 0$. Two features of this problem are immediately apparent. Firstly, the military authority should pay no more than it need to to secure a particular quantity, variety and quality; therefore the participation constraint must bind. Secondly, symmetry prevails among those firms chosen so $p_j = p$, $d_j = d$, and $q_j = q$ for all of the n chosen firms. The participation and budget constraints are therefore

$$p = c + \frac{F + f q^{\beta}}{d} \tag{5}$$

$$npd = G \tag{6}$$

and the military authority maximizes

$$M = n^{\frac{1}{\alpha}} qd \tag{7}$$

with respect to n, d, p and q given (5) and (6). Eliminating p and d from the two binding constraints reduces the problem to maximizing

$$M = \frac{n^{(\frac{1}{\alpha}-1)} q}{c}(G - nF - nfq^{\beta}) \tag{8}$$

with respect to n and q. The first-order conditions for this problem are:

$$(\frac{1}{\alpha} - 1)n^{(\frac{1}{\alpha}-2)}q(G - nF - nfq^{\beta}) - n^{(\frac{1}{\alpha}-1)}q(F + fq^{\beta}) = 0 \tag{9}$$

$$n^{(\frac{1}{\alpha}-1)}((G - nF - nfq^{\beta}) - n^{(\frac{1}{\alpha}-1)}fn(\beta + 1)q^{\beta} = 0 \tag{10}$$

which yields the solution for the optimal number of firms

$$n = \frac{G}{\beta F}[\beta(1 - \alpha) - \alpha] \tag{11}$$

the quantity of each weapon

$$d = \frac{\alpha \beta F}{c[\beta(1 - \alpha) - \alpha]} \tag{12}$$

price

$$p = \frac{c}{\alpha} \tag{13}$$

quality

$$q = \left[\frac{G - nF}{nf(\beta + 1)}\right]^{\frac{1}{\beta}} = \left[\frac{\alpha F}{f[\beta(1 - \alpha) - \alpha]}\right]^{\frac{1}{\beta}} \tag{14}$$

and the total number of weapons produced

$$nd = \frac{\alpha G}{c} = \frac{G}{p}. \tag{15}$$

The second-order condition is $M_{nu}^2 < M_{uu}M_{nn}$ where subscripts here denote partial derivatives. A little algebra shows that this is satisfied at the turning point if $(\beta + 1)(1 - \alpha) > 1$, i.e., $\beta + 1 > \sigma$. This is precisely the condition for $n > 0$. In what follows we assume this condition is satisfied.

Clearly the number of firms n falls as G falls, or F rises or α rises. Furthermore, differentiating (11) we have

$$\frac{\partial n}{\partial \beta} = \frac{\alpha G}{F\beta^2} > 0 \tag{16}$$

and so n falls as β falls. From (14) a fall in the number of firms is associated with a rise in quality. The intuition behind the result relating the number of firms to β is that quality, as well as quantity, is a substitute for product diversity in achieving military capability. A military authority maximizing the latter will therefore exploit this trade-off. An optimal response to a drop in government spending is to forgo some diversity and concentrate production in fewer production units of a greater size, but producing higher quality weapons. This achieves savings in fixed costs, reduces diversity but is compensated by the higher quality. The total size of the industry, given by (15), depends only on the size of the budget and the procurement price. Price rises with marginal cost and, as α falls, with the monopolistic power of the firm. For given military expenditure, a more competitive market (resulting for instance from reduction in national preferences or better ability to substitute between different types of weapons) reduces price and increases the quantity of weapons in the world.

We summarise these results in the following proposition:

In the world economy concentration increases (the number of firms falls and their size rises) if total military expenditure G falls, fixed costs F rise, military goods become more homogeneous ($\alpha \to 1$) and the quality cost parameter β falls. A fall in the number of firms is associated with a rise in quality. The size of the industry depends only on total military spending (positively) and on the monopoly power of the firm (negatively).

Although the model is very simple it allows us to analyse the relationship between the relevant set of variables: total demand, fixed costs, the effectiveness of R&D, competition and concentration. However it is important to be aware of what the model does not do. Firstly, in this model firms do not behave strategically, thus the increase in concentration and competition is not driven by the strategic behaviour of firms. This is quite unlike the case of telephone switches analysed in Sutton (1998, ch5). Normally in high R&D industries one would expect β to be low: because the extra quality obtained per unit of R&D is high, it is profitable to invest in R&D. But this applies to R&D done by firms to give them a competitive advantage over other firms. In the arms industry R&D is chosen by governments to give them a military advantage over their adversaries. Even if β is large, so that the last 1% of performance enhancement is very expensive, that slight quality advantage may be worth having in combat. Kirkpatrick (1995) discusses this in more detail. This makes defence a high R&D industry with high β. Secondly, the model does not explain the industrial dynamics associated with the rise in concentration, e.g. the process of mergers and acquisitions. We have assumed each firm produces a single variety, but in practice, firms may produce more than one variety and there may be economies of scope.

Dunne et al (2003) considers many of these issues and develops the modelling accordingly. In this paper we move on to analyse the available empirical information on the restructuring of the market.

6 The evolution of concentration

To analyse the changing structure of the arms market the best available source of data is the SIPRI arms company database. SIPRI have collected information on arms sales, total sales, profits and employment for the 100 largest arms-producing companies since 1988. They send questionnaires to companies asking them for the information. In the case of the share of arms in total sales, companies may be unwilling to disclose this and in such cases estimates are used, with the assistance of a network of country experts.

As Table 2 shows the five largest companies in the SIPRI list accounted for 22% of arms production by the top 100 in 1990. This is very close to Sutton's independent sub-market lower bound for the five firm concentration ratio given above above, which is 20%, similarly the 10 firm and 15 firm ratios are close to their lower bounds of 33% and 43%. At the end of the Cold War the international arms industry was not very concentrated. It is noticeable that the concentration in total sales was higher than in arms sales: commercial markets are more concentrated than military markets even though the commercial markets these firms were operating in were very different. In 2002, the five largest arms firms accounted for 40% of the total. This large increase in the share of the top companies is continued further down the sizes, as shown for the largest 10,15,and 20 and indeed across the distribution of the companies as shown by the Lorenz curves in the Appendix. There was also an increase in concentration for total sales, but not by as much, since it started from a higher base. 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 2: Concentration

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

One would expect an increase in concentration following a fall in demand, but this does seem a rather large increase given the size of the fall in demand. What seems more likely is that by its nature major weapons systems would naturally be a very concentrated market like pharmaceuticals, civil airliners, etc., but that the role of the national governments in attempting to maintain national defence capabilities has been to prevent the inevitable concentration. If the increase in concentration is to be seen as an adjustment to some equilibrium market structure, then this would be reflected in the dynamics of the sample. We would expect to find that the growth of the firms showed no clear pattern that suggested strategic successes of companies, but a general change across the whole size distribution.

The degree of change in the international arms industry is further illustrated in Table 3, 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 company declining from $187 billion to $158 billion, while the top 3 companies almost doubled their arms sales.

Table 3

			1990	2000	1990	2000	%Change
1	McDonnel Douglas	USA	1	-	9890	-	-
2	BAE Systems	UK	2	3	8710	14400	65.3
3	General Dynamics	USA	3	6	8300	6520	-21.4
4	Lockheed Martin	USA	4	1	7500	18610	148.1
5	General Motors	USA	5	49	7380	540	-92.7
6	General Electric	USA	6	20	6450	1600	-75.2
7	Raytheon	USA	7	4	5500	10100	83.6
8	Thales	Fr	8	8	5252	5160	-1.8
9	Boeing	USA	9	2	5100	16900	231.4
10	Northrop Grumman	USA	10	5	4930	6660	35.1
11	United Technologies	USA	13	11	4100	2880	-29.8
12	Litton	USA	19	9	3000	3950	31.7
13	TRW	USA	20	10	2980	3370	13.1

Developing the analysis to consider a wider set of companies we consider all companies that were in the top 100 list between 1990 and 1998. When computing growth rates over the period, however, only companies alive over that period can be considered. There are also missing values for some of the variables for some of the companies and hence the sample sizes will differ when we provide descriptive statistics for each of the variables. Starting from a list of companies that were in the top 100 in one or both of the years gave a sample of 125 companies. This includes companies that 'died' before 1998, companies that were 'born' after 1990, subsidiary companies and companies that have missing information. Taking out the companies that are subsidiaries owned by companies in the Top 100 and looking at only those companies that were alive in 1990, left us with a sample of 100 in that year of which 81 survived to 1998.

This sample shows an increase in concentration in Table 4. There was an increase in the average share of both arms sales and total sales between the two years as well as a marked increase in the spread of the distribution of shares, represented by the coefficient of variation. The Herfindahl index of concentration more than doubled for arms sales, increasing a little less for total sales

Table 4: Concentration measures

All companies	1990 Arms	1990 Sales	1998 Arms	1998 Sales
Number of companies	98	92	78	81
Average ($1995)	1875.4	11607.4	1808.9	14436.1
Coeff of Variation	1.09	1.61	1.80	1.98
Herfindahl	0.022	0.039	0.054	0.069

Survivors	Arms 1990	Arms 1998	Sales 1990	Sales 1998
Number of companies	63	63	60	60
Average ($1995)	1864.9	1634.0	11913.9	15500.2
Coeff of variation	1.09	1.59	1.67	1.98
Herfindahl	0.034	0.055	0.063	0.081

As Table 5 shows the fall in average arms sales over the period was just over 28%, but that this fall was not reflected in total sales, which grew by 7%, with employment falling by 25%. The average fall in the share of arms sales in total sales reported by SIPRI was 7%. The growth in arms sales was computed using the log difference between the two years which left a sample of 65 companies, the other computations differ in the number of companies included because of missing values.

Table 5: Growth 1990-98

	Growth Arms	Sales	Employ	Civil	Change in Arms share
Average	-0.284	0.074	-0.250	0.250	-6.6
Min	-2.940	-1.523	-1.233	-1.780	-72.0
Max	49.4	44.2	86.1	53.1	75.0
Coeff of var					
Number co.s	63	60	55	59	65

Table 6 presents a transition matrix that allows an analysis of the movements of companies across size classes over the period. Reading across the rows gives the number of firms in a particular size group in 1990 and down the columns, the number in 1998. Thus the diagonal represents the number of firms that stayed in the same size group over the period. The next to last columns gives the size groups in 1990 of those firms that exited the market prior to 1998. This shows that the majority of companies exiting were in the second and third size class, small to medium producers.

Table 6: Transition Matrix: Arms Sales, $00

	0-5	5-10	10-20	20-30	30-40	≧ 40	Exit	Total
0-5	12	3	0	0	0	0	5	20
5-10	6	10	1	0	0	0	10	27
10-20	2	5	6	1	0	0	10	24
20-30	0	0	1	2	0	1	5	9
30-40	0	0	0	2	2	0	0	4
≧ 40	1	1	1	0	0	6	5	14
Total	21	19	9	5	2	7	35	98

Transition Matrix: Total Sales

	0-1	1-5	5-10	10-15	15-20	≧ 20	exit	Total
0-1	9	2	0	0	0	0	3	14
1-5	0	20	0	0	0	0	14	34
5-10	0	1	7	1	0	0	6	15
10-15	0	1	1	0	1	2	3	8
15-20	0	0	0	2	0	2	2	6
≧ 20	0	1	0	0	1	9	4	15
Total	9	25	8	3	2	13	32	92

One interesting issue is the degree to which these changes in the size distribution represent changes in corporate strategy. As we have discussed companies could respond to the decline in arms sales by diversifying into civil production, as some did though with mixed success. Alternatively, they could diversify into arms production, which again some did. Classifying the companies as:

- Winners: increasing arms sales and increasing civilian sales
- Diversifiers: declining arms sales and increasing civilian sales
- Rearmers: increasing arms sales and decreasing civilian sales
- Losers: decreasing arms sales and decreasing civilian sales

Diversifiers could be converting plants, diversifying by organic growth or acquisition or divesting their arms sales. We used estimated civil production of the sample and considered the frequency distribution for these categories both for those companies with increasing arms shares and for those with decreasing arms shares. Interestingly, 9 of the 11 companies that showed both increasing arms sales and increasing civil sales showed a decreasing share in their arms sales, meaning they became less important to the company. The diversifiers make up the largest group and the losers are evenly spread between increasing and decreasing arms shares.

Table 6:

	Increasing Arms Share	Decreasing Arms Share	Total
Winners	2	9	11
Diversifiers	0	33	33
Rearmers	6	0	6
Losers	4	3	7
Total	12	45	57
Exits			33
			90

To consider the dynamics of the industry further we need to focus on the growth rates of the companies and to choose a framework for the analysis. This is undertaken in the next section.

7 Econometric issues

A useful approach for analysing the growth of companies is an empirical analysis within the framework of testing Gibrat's law (Dunne and Hughes, 1994 and Sutton, (1997), Caves (1998) provide reviews). This approach was used in the 1970s to analyses the reasons for an observed inexorable rise in concentration of manufacturing industry,. There was a concern that this would continue and lead to increasing monopoly power Hannah and Kay (1977). In fact as this problem was identified things were changing and there was a steady rise in the share of smaller firms in total output taking place. Gibrat's law states that the probability distribution of growth rates was the same for all sizes of firms.

$$\frac{S_{it}}{S_{it-1}} = \varepsilon_{it}$$

This can be tested by writing it as:

$$logS_{it} = \alpha \ + \ \beta \log S_{it-1} + \varepsilon_{it}$$

and testing if $\beta = 1$. If $\beta < 1$ smaller firms are growing faster than the larger firms and if $\beta > 1$ the larger firms are growing faster than the smaller firms. This can also be reparameterised as a growth rate equation

$$\Delta \log S_{it} = \alpha + (\beta - 1) \log S_{it-1} + \varepsilon_t$$

in this case the test is for the coefficient on $\log S_{it-1}$to be zero.

Another way of interpreting these regressions is to consider the model in log deviations form. define

$$\begin{aligned} y_{it} &= \log S_{it} - \log S_t \\ \log S_t &= N^{-1} \sum_{i=1}^{N} \log S_{it} \end{aligned}$$

then

$$y_{it} = \beta y_{it-1} + \varepsilon_{it}.$$

Squaring, summing over i and dividing by N, and taking expected values, noting that ε_{it} is independent of y_{it-1} gives

$$E(\frac{\sum y_{it}^2}{N}) = \beta^2 E(\frac{\sum y_{it-1}^2}{N}) + E(\frac{\sum \varepsilon_{it}^2}{N})$$

which gives the relationship determining the evolution of the variance of log firm size:

$$\sigma_t^2 = \beta^2 \sigma_{t-1}^2 + \sigma_\varepsilon^2.$$

This implies

$$1 = \beta^2 \frac{\sigma_{t-1}^2}{\sigma_t^2} + \frac{\sigma_\varepsilon^2}{\sigma_t^2}$$

or

$$\beta^2 \frac{\sigma_{t-1}^2}{\sigma_t^2} = 1 - \frac{\sigma_\varepsilon^2}{\sigma_t^2}.$$

The right hand side of this equation is the the R^2 of the cross-section regression, so

$$\frac{\sigma_t^2}{\sigma_{t-1}^2} = \frac{\beta^2}{R^2}$$

This means that the evolution of the variance of log size, a measure of concentration, is determined by the ratio of the R^2 to β^2. Whether the variance increases or decreases depends both on β and the size of the stochastic shocks. If $\beta = 1$, as implied by Gibrat's law the ratio of current to previous variance is $1/R^2$ which must be positive so variance and concentration is increasing through time.

The way the model is formulated it is only possible to include companies that survive over the whole period. However, if the non surviving companies share certain characteristics, such as they are slow growing then this can obviously bias the estimation results. More formally, what we have is:

$$\begin{aligned} logS_{it} &= \alpha + \beta \log S_{it-1} + \varepsilon_{it} \text{ if } S_{it} > 0 \\ &= 0 \text{ otherwise} \end{aligned}$$

thus

$$E(\log S_{it} \mid \log S_{it-1}, S_{it} > 0) = \alpha + \beta \log S_{it-1} + E(\varepsilon_{it} \mid S_{it} > 0)$$

with

$$\varepsilon_t \sim N(0, \sigma^2)$$

This can be written as

$$E(\log S_{it} \mid \log S_{it-1}, S_{it} > 0) = \alpha + \beta \log S_{it-1} + \sigma\lambda_i$$

where

$$\lambda_i = \frac{f(V_i)}{1 - F(V_i)} \text{ and } V_i = [\frac{\alpha + \beta \log S_{it-1}}{\sigma}]$$

with $f(..)$ the density function for the standard normal and $F(..)$ the distribution function for the standard normal. If there is sample selection bias and we were to estimate a simple OLS regression omitting $\sigma\lambda_i$ giving biased and inconsistent estimators.

For the two stage procedure let

$$\begin{aligned} d_i &= 1 \text{ when } S_{it} > 0 \\ d_i &= 0 \text{ otherwise} \end{aligned}$$

Then we can set up a likelihood function

$$\begin{aligned} L &= \Pi_{i=1}^{N} [\Pr(\varepsilon_i \leqslant -V_i]^{1-d_i} [\Pr(\varepsilon_i \leqslant -V_i]^{d_i} \\ &= \Pi \; F\left[\frac{V_i}{\sigma}\right]^{d_i} \; \left\{1 - F\left[\frac{V_i}{\sigma}\right]\right\}^{1-d_i} \end{aligned}$$

As $F(-t) = 1 - F(t)$ this is the likelihood function for the probit estimation on d_i and $E(d_i) = V_i/\sigma$. So we estimate a probit:

$$\Pr(d_i = 1) = P(V_i)$$

compute V_i and

$$\lambda_i = \left[\frac{f(V_i)}{1 - F(V_i)}\right]$$

For the second stage we use the consistent estimator of λ_i, $\widehat{\lambda}_i$ to estimate

$$E(S_{it} \mid S_{it-1}, S_{it} > 0) = \alpha + \beta S_{it-1} + \sigma\widehat{\lambda}_i$$

giving a consistent estimator of β.

It is also possible to use a maximum likelihood method , that uses this consistent estimator as a starting value to search for a solution on the highly non-linear likelihood function;

$$L = \Pi_{d_i=0} F\left(-V_i, \sigma^2\right)\ \Pi_{d_i=1}\left(S_{it} - V_i, \sigma^2\right)$$

now as $1 - F(-V_i, \sigma^2) = 1 - F(V_i, \sigma^2)$ which we call $1 - F_i$

$$L = \sum_{d_i=0} \ln(1 - F_i) - \frac{N - S}{2} ln\sigma^2 - \frac{1}{2\sigma^2} \sum_{d_i=1} \left(S_{it} - V_i, \sigma^2\right)$$

which can be solved using an iterative process such as Newton Raphson.

8 Estimation Results

To use the law of proportionate effects approach the first, 1990, and last year, 1998 of the sample are taken for each company and the following equation is estimated

$$logS_{it} = \alpha + \beta \log S_{it-1} + \varepsilon_{it}$$

Both $logS_i$ in 1990 and in 1998 are close to normal. Skewness in the unconditional distribution in 1990 is 0.51 and in 1998 0.74; kurtosis is 2.48 and 3.00. Given the nature of the companies with their close relation to he national government it would seem worth introducing dummy variables to reflect the ownership of the companies. Dummy variables were created which take the value of one for the major arms producing companies companies and zero otherwise:

$$logS_{it} = \alpha + \beta \log S_{it-1} + \gamma_1 DUS + \gamma_2 DUK + \gamma_3 DFR + \gamma_4 DGR + \varepsilon_{it}$$

As both an observation for 1990 and 1998 are needed for this regression only the companies that survive for the whole period and do not have missing values for the relevant variable in either year are included. For arms sales this gives around 84 observations and for total sales about ten fewer observations. The results are presented in Table 7.

Table 7: Estimates for Surviving Companies, dependent variable log sales N=63 for arms, N=60 for total.

	α	β	γ_1	γ_2	γ_3	γ_4
Arms	0.53	0.88	-0.18	0.48	-0.04	0.21
(t)	0.77	8.53	-1.16	2.96	-0.26	1.31
Total	0.05	0.99	0.07	-0.13	0.02	0.54
(t)	0.27	24.08	0.49	-0.75	0.13	2.74

The total equation fits better with an $\overline{R}^2$ of 0.91 compared to 0.65 for the arms sales. The hypothesis that $\beta = 1$ cannot be rejected in either case (with t ratio of -1.11 for arms sales and -0.22 for total sales). There was some evidence of heteroscedasticity, so robust standard errors were used. These results do seem to support the hypothesis that the probability distribution of growth rates was the same for all sizes of firms. There are, however, some country specific effects, though the only significant coefficients on the dummies are for the UK in the total sales regression and Germany in total sales. The results suggest a growth in concentration in the sample of companies, but with no difference in growth rates across size classes. This is true for both arms sales and total sales. There is some evidence that the UK companies had a higher growth rate than the other countries in total sales and Germany a higher growth total sales. There is no evidence of any US specific effect. This is somewhat strange given the rapid concentration in the US. However, separate regressions on the US and non US samples for the 59 companies with both total sales and arms sales data in both periods suggests some differences. For the US companies the estimate of β, (standard error of β) was 0.78 (0.21) with a standard error of regression of 0.87, for non-US companies the estimates were 0.98 (0.07), with a standard error of regression of 0.39. Non-US firms stayed the same, small US firms grew relatively faster, size of arms sales in 1990 predicted size in 1998 much better for the non US firms than for the US firms. This difference deserves further investigation but we will return to the combined sample.

As we have discussed it is possible for the results to be biased by sample selection effects. Estimating a probit model with survive/not survive as the dependent variable and the value of the size variable in 1990 proved to be a rather poor model. As it is possible that survival may be a nonlinear function of size a squared term was entered

$$\Pr(d_i = 1) = \Phi(\delta_1 + \delta_2 s_{it-1} + \delta_3 s_{it-1}^2)$$

This worked better though the probabilities are still poorly defined, especially for the arms sales. Investigation of the factors that determine survival requires further investigation.

Table 8: Probit survival estimates

	N	$Survive$	δ_1	δ_2	δ_3
$Arms$	100	65	10.5	-2.73	0.18
(t)			1.19	-1.12	1.10
$Total$	97	63	9.43	-2.09	0.12
(t)			1.72	-1.63	1.60

Using these probit results to provide the Mills ratio for the sample selection procedure gave the following results.

Table9: Sample Selection Estimates
N=65 for Arms N=63 for Total

	α	β	γ_1	γ_2	γ_3	γ_4	σ	$\overline{R}^2$	$\frac{\beta^2}{R^2}$	$t_{\beta=1}$
$Arms$	0.38	0.86	-0.17	0.52	-0.05	0.22	0.60	0.65	1.07	-1.36
(t)	0.54	8.11	-0.89	1.97	-0.22	0.78	0.53			
$Total$	0.14	1.00	0.08	-0.12	0.04	0.55	-0.21	0.90	1.09	-0.07
(t)	0.35	22.2	0.58	-0.60	0.19	2.62	-0.40			

In none of the four cases is sigma significantly different from zero, suggesting that the results are not sensitive to sample selection bias over this period. These estimates from the Heckman two stage procedure are consistent, but not fully efficient. As outlined above maximum likelihood estimates can be obtained from LIMDEP, which use the Heckman procedure to provide starting values and these are presented in Table 10. The results are little different to the previous ones, apart from γ_2 the UK dummy coefficient becoming insignificant in the arms sales equation.

Table 10: Maximum Likelihood Estimates

	N	δ_1	δ_2	δ_3
Arms	98	11.3	-2.96	0.20
(t)		1.30	-1.26	1.24
Total	92	3.11	-0.66	0.04
(t)		0.52	-0.48	0.49

	α	β	γ_1	γ_2	γ_3	γ_4	σ	ρ	$t_{\beta=1}$
Arms	0.49	0.88	-0.18	0.49	-0.04	0.22	0.57	0.24	-1.28
(t)	0.55	9.24	-0.64	1.14	-0.11	0.42	4.27	0.13	
Total	0.16	1.03	0.18	-0.04	0.04	0.59	0.60	-0.96	0.19
(t)	0.25	15.0	0.96	-0.16	0.15	2.32	8.26	-20.6	

Sales of arms and total sales may interact. To allow for this we introduce, lagged total sales, S in the arms sales, A, equation and lagged arms sales in the total sales equation. This gives the equations:

$$\log A_{it} = \alpha+\beta\log A_{it-1}+\delta S_{it-1}+\gamma_1 DUS+\gamma_2 DUK+\gamma_3 DFR+\gamma_4 DGR+\varepsilon_{1,it}$$

$$\log S_{it} = \alpha+\beta\log S_{it-1}+\delta A_{it-1}+\gamma_1 DUS+\gamma_2 DUK+\gamma_3 DFR+\gamma_4 DGR+\varepsilon_{2,it}.$$

The results are given in Table 11.

Table 11: Explaining log sales, N=59.

	α	β	δ	γ_1	γ_2	γ_3	γ_4
Arms	0.61	0.90	-0.02	-0.20	0.48	0.03	0.22
(t)	0.75	10.0	-0.29	-1.22	2.81	0.19	1.29
Total	0.56	1.05	-0.15	0.15	-0.07	0.10	0.63
(t)	1.39	21.7	-1.96	0.99	-0.36	0.77	2.95

As before, the total sales equation fits much better than the arms sales equation, $\overline{R}^2 = 0.91$ against 0.61 for arms. The hypothesis that the coefficient of the lagged dependent variable is unity is not rejected in either case, $t(\beta = 1) = -1.15$ for arms and 1.05 for total sales. Lagged total sales is negative but not significant in the arms sales equation, lagged arms sales is negative and significant in the total sales equation. Companies with large relative arms sales in 1990 grew slower than other companies of the same size. When the arms sales equation is split by US and non-US as before, the the non-US relationship continues to have a much smaller standard error, total sales have a significant positive effect for non-US companies. For US companies total sales have a negative and insignificant effect, but including them raises β to just above unity, rather than 0.78 when they are excluded.

9 Conclusions

At the end of the Cold War, the international arms industry was relatively unconcentrated by comparison with comparable high technology industries like commercial aerospace or pharmaceuticals. In fact it was quite close to the Sutton lower bound. The main reason for this was probably the tendency for the major military powers to prefer to procure from national defence industries. The decline in the total size of the market and the tendency for R&D requirements for major weapons systems to rise produced an increase in concentration, with the five firm concentration ratio raising from just over 20% to over 40%. The way concentration increased differed in the US and Europe. However, the industry is still not very concentrated by comparison with comparable industries and the economics suggest that concentration will continue. This is likely to raise some difficult political issues as countries face powerful international arms monopolies. The preliminary econometric work we conducted did not reject the hypothesis that for a company its growth rate of arms sales was independent of its initial level of arms sales, but there is clearly scope for further work.

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