Global Production Networks in the Aerospace Industry: The Role of Risk and Revenue Sharing Partnerships

ABSTRACT

The last 30 years have seen a major trend towards the internationalisation of production. In some industry sectors this process has become global as production systems have been integrated on an inter-continental basis. Global production networks have been identified as an important factor in this development. A number of studies have explored the use of global production networks in sectors such as clothing and textiles, electronics and automotive products. In general this research has been confined to consumer items that take the form of standardised, high volume commodities.

This study in contrast, examines the use of global production networks by capital goods manufacturers producing non-standardised, high technology products in relatively small volumes. The context is the commercial aerospace industry and an in-depth case study of a single manufacturer, the UK based engine maker Rolls-Royce and the global production network used to develop and manufacture its Trent 1000 engine for the Boeing 787 Dreamliner, is presented. The study focuses on the use of risk and revenue sharing partnerships (RRSPs), a form of inter-firm collaboration almost unique in the aerospace industry. It analyses the role of RRSPs in facilitating the creation and operation of global production networks and the driving forces that have led to the use of this form of cooperation. The implications of the move to global production networks are considered both for flagship firms at the centre of such networks and their partners.

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INTRODUCTION

The internationalisation of production in the aerospace industry has a long history. In the case of military aerospace contracts, manufacturing under licence and offset agreements have long been used to support export programmes. However such arrangements typically amount to little more than token internationalisation, since rarely is anything more than assembly operations or component production internationalised. In any event such arrangements were not to be found in the commercial aerospace sector. One of the first moves towards internationalisation, was Rolls-Royce s planned but subsequently abandoned, joint venture with General Motors of the US (Smith 2007, p. 675) to develop a large, high thrust engine, the RB211.

In the commercial aerospace sector the process of internationalisation really started in the 1970s with the creation of the Airbus consortium to development and manufacture the A300 twin jet airliner. It brought together Aèrospatiale of France (37.9 per cent), Germany s DASA (37.9 per cent), the UK s Hawker-Siddeley Aviation (20 per cent) and CASA of Spain (4.3 per cent) (Hayward 1986, p.67). The decade also saw moves towards internationalisation on the part of the engine manufacturers. The first commercial jet engine to be developed on a truly international basis, resulted from the formation of CFM International, a joint venture between General Electric of the US and SNECMA of France (Mowery 1987). The international nature of the project was reflected in the setting up of two assembly operations, one in the US and the other in France. Britain s Rolls-Royce also became involved in engine development on an international basis through a joint venture with the Japanese firms, Mitsubishi, Kawasaki and Ishikawajima-Harima, to develop the RJ500 engine (Garvin 1998, p.154).

The 1980s saw further moves towards internationalisation in the aero engine sector, again based on joint ventures involving leading engine makers. The most ambitious venture was the creation of International Aero Engines (IAE) in 1983, a joint venture which brought together two project teams, one of which involved Pratt and Whitney of the US, together with

Germany s MTU and Italy s Fiat Avio, the other Britain s Rolls-Royce and Japanese partners, Mitsubishi, Kawasaki and Ishikawajima-Harima. Although Rolls-Royce and Pratt and Whitney were the senior partners, with 30 per cent shares each (Mowery 1987, p.90), this programme was truly international, not only because the partners were from Europe, North America and Asia, but because all the partners played an active part in design and development as well as manufacture. During the course of the decade Rolls-Royce extended its international involvement through two further joint ventures, one with Williams International of the US and the other with BMW of Germany (Smith 2003). This was not a pattern repeated in the airframe sector where, despite a number of false starts, Airbus remained the only aircraft manufacturer with production facilities spread across several countries.

During the late 1990s and early 2000s the trend towards internationalisation of production in the aerospace industry continued , but not through the use of joint ventures. Instead in both the airframe and engine international cooperation took place through risk and revenue sharing partnerships (RRSPs). Notable examples were Brazil s Embraer and latterly Boeing in the US. In Embraer s case its E170/190 regional jet was developed in the late 1990s through a RRSP involving 16 partners from seven countries who contributed 36 per cent of the $850million development costs of the project (Figueiredo et al. 2008, p.33). Development and manufacture was truly international with the wings produced by Kawasaki in Japan, the centre fuselage by Sonaca in Belgium, the rear fuselage by Latecoere in France and the empennage by Gamesa in Spain. In the engine sector the development of a series of ultra high thrust engines for a new generation of wide-bodied jets, such as the Boeing 777 and the Airbus A380, led all three engine makers to use RRSPs to develop new engine programmes. Rolls-Royce was at the forefront of this movement, both in terms of number of partners engaged and the proportion of work undertaken by them.

One of these engine programmes, the Trent 1000 engine for the Boeing 787 Dreamliner forms the focus of this study. It provides an in-depth case study, in order to examine the nature of RRSPs and the part they play in facilitating in the creation of global production networks. The study also analyses the driving forces that have led to the use of this form of cooperation and considers the implications of the move to global production networks both for flagship firms at the centre of such networks and the upgrading of local capacity on the part of partner firms.

LITERATURE REVIEW

Global production networks (GPNs) are defined by Coe et al. (2008, p.274) as, „the nexus of interconnected functions, operations and transactions through which a particular product or service is produced, distributed and consumed . In short GPNs involve the outsourcing of functions. They are the product of strategic fragmentation whereby formerly vertically integrated businesses through a process of long distance coordination disperse some of the value adding stages of the production process between firms and across geographic space. A number of factors during the course of the 1980s and 1990s stimulated the outsourcing of activities in this way, including: trade liberalization, exogenous political transformations particularly the move to market economics on the part of Communist countries and major improvements in transport and communications (Lane and Probert 2009).

The concept itself owes much to earlier conceptualizations, specifically global commodity chains (GCCs) and global value chains (GVCs) (Hess and Yeung 2006). The term GCC originated with the American sociologist Gereffi (1994; 1999), building on Hopkins and Wallerstein s (1977) work on world systems in the production and distribution of food commodities. Hence the GCC takes a systems perspective which in the case of agriculture based commodities seeks to link together three discrete systems that operate at different levels, namely: farms and farm systems; food processing; and retailing and branding.

A major focus of Gereffi s (1994) work is on issues surrounding the governance of the chain (Henderson et al. 2002). He identifies two types of governance structure, buyer-driven and producer-driven. Producer-driven GCCs tend to be found in capital/technology intensive industries like electronics and automobiles and involve large multinational corporations who control tightly integrated production systems. Buyer-driven GCCs in contrast are found in labour intensive consumer goods industries such as clothing and footwear, and involve large retailers and brand merchandisers. Good examples are the American retail giant Wal-Mart and the sportswear firm Nike. Businesses like these own no production facilities themselves, but their power lies in their ability to coordinate a dispersed network of independent and quasi-independent manufacturers. Dicken et al. (2001, p.99) note that in fact the range of empirical research has focused overwhelmingly on buyer-driven chains, particularly those associated with clothing and footwear (Lane and Probert 2009).

Latterly there has been a recognition that the word commodity is too restrictive since it has connotations of standardized products (Henderson et al. 2002) and the term global value chain (GVC) has been used instead (Kaplinsky 2000). This relies heavily on the work of management scholars such as Kogut (1984) and Porter (1985). The GVC approach focuses not on systems, but rather on activities, specifically the chain of incremental activities that a firm engages in to bring a product to market. Although value chains as conceived by Porter (1985) were at one time largely internal to the firm, Kogut s analysis showed firms global strategies have increasingly focused on placing activities within the value chain in different countries. According to Lane and Probert (2009, p. 25) one of the principal merits of GVC analysis is the way it focuses on differential value extraction at various points in the value chain. With buyer-driven chains especially this involves wage differentials between developing and developed countries. Applications of GVC analysis have tended therefore tended to focus again on commodity products such as clothing although they have also included studies of technology-based consumer product such as electronics (Dedrick et al. 2009).

However an increasing number of scholars (Dicken et al. 2001; Ernst and Kim 2002; Henderson et al. 2002) have questioned the „chain as an analytical concept noting that it has a number of weaknesses, in particular the emphasis on linearity and sequential activity (Coe et al. (2008). For this reason there has been a move to the use of the broader term global production network (GPN), precisely because it operates at a variety of different levels and affords a greater degree of autonomy for economic actors, such as firms. In fact the concept of a GPN offers a number of advantages over earlier conceptualisations. Bowen (2007, p.313) details these as: the ability to map the creation and capture of value across firms and spaces; the emphasis on „back and forth traffic in materials, information and value; and the ability to capture the multi-directional exercise of power (Dicken et al. 2001; Henderson et al. 2002) by firms and places engaged in production.

The introduction of the concept of the GPN has resulted in empirical research that stretches across a broader range of industries than seen in the past. In particular capital/technology intensive sectors have increasingly come within the remit of major studies. Hence there have been studies of the automotive sector (Busser and Sadoi 2004) and various branches of electronics (Borrus et al. 2000). The most capital intensive sectors producing capital goods such as aerospace however, have still been largely ignored. One exception is the study by

Bowen (2007) which analyses the GPNs used by commercial airliner manufacturers like Boeing. Although it provides details of the GPN used by Boeing to develop its new 787 Dreamliner, it focuses on the role of Asian countries, and says little about governance particularly the role of institutional arrangements such as risk and revenue sharing partnerships (RRSPs) which Herzog (2010) notes are an important feature of this type of international cooperation in the aerospace industry.

In the light of this, this study seeks to fill this gap by examining in detail a major aerospace programme in order to analyse its governance arrangements and the factors that have led to the creation of this particular form of global production network.

CASE STUDY: ROLLS-ROYCE'S TRENT 1000 ENGINE PROGRAMME

The Trent 1000 engine is the fifth member of Rolls-Royce s Trent family (see table 1) of ultra high thrust engines that power the new generation of wide-bodied airliners introduced over the last ten or so years. It powers Boeing s new medium-sized twin jet airliner, the 787 Dreamliner. This new Boeing airliner aims to apply the same advanced lightweight structure, improved systems technology and high efficiency engines planned for the short-lived Boeing Sonic Cruiser to a conventional airliner. Whereas the proposed Sonic Cruiser was a futuristic design able to offer greater speed and therefore shorter journey times, the 787 is a „future efficient transport (Lawrence and Thornton 2005:, p. 100) able to offer airlines substantially lower operating costs.

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Insert Table 1

The development schedule of the new 787 was initiated in December 2002 when the Boeing board dropped the proposed Sonic Cruiser in favour of a „super efficient airliner , the 7E7, as the 787 was originally designated. (Norris and Wagner 2009, p. 35). All three of the leading engine makers, General Electric and Pratt and Whitney of the US and Britain s Rolls-Royce, were invited to submitted proposals for engines to power the 787 Dreamliner in February 2003. They were faced with a demanding design brief, as the 787 offered improved efficiency amounting to a 20 per cent saving in fuel, compared to comparable aircraft then flying such as the Airbus medium-sized jet the A330 (Nicholls, 2005). While much was made of the high proportion of carbon fibre composites being used on the airframe and the replacement of pneumatic systems with electric ones, in fact the engines were required to provide 80 per cent of the airliner s improved efficiency (Norris and Wagner 2009, p.93). In the event General Electric proposed a derivative of its largest engine the GE90 and Rolls-Royce too came forward with a derivative design in the form of the Trent 1000. Pratt and Whitney meanwhile opted for an all new design, the PW-EXX. Although Boeing initially toyed with the idea of sole sourcing the powerplant of the 787, pressure from potential customers resulted in two engines being selected by Boeing in April 2004, General Electric s GEnx and Rolls-Royce s Trent 1000.

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Insert Figure 1

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The inherent flexibility of the three shaft configuration of Rolls-Royce s Trent engine family permitted the use of a derivative design for the Trent 1000, based around a scaled up core of an existing engine, the Trent 500 (see figure 1). In addition the Trent 1000 borrowed extensively from advanced technologies originally developed for other Rolls-Royce engines. To gain the necessary improvement in fuel efficiency and de-rate the power output, the Trent 1000 engine used a new 112 ins fan, comprising 20 curved hollow titanium fan blades, similar to the ones developed initially for the Trent 8104 demonstrator engine. These gave the engine a bypass ratio of 10:1 almost double that of the first Trent engine the Trent 700. Like the Trent 900 engine for the Airbus A380, the Trent 1000 utilized a contra-rotating high pressure spool (Kandebo 2004). To meet the much increased requirement for electrical generation resulting from the „all-electric features of the 787 (Norris and Wagner 2009, p.76), the engine had a unique power take-off (Rolls-Royce 2005, p. 13) driven directly off the intermediate pressure (IP) compressor.

Having succeeded in getting its engine selected for the new Boeing jet in April 2004, Rolls-Royce scored another major success in October of the same year, when the Trent 1000 became the lead engine on the 787 following its selection by Japan s All Nippon Airways (ANA) (Norris and Wagner 2009, p. 98) to power its order for a total of 50 jets. This was the first time a Boeing wide-bodied jet had been launched with a Rolls-Royce engine.

The previous month, in September 2004, it was announced that the Japanese firm Mitsubishi had agreed to become a partner in a risk and revenue sharing partnership (RRSP) being established by Rolls-Royce to develop and manufacture the Trent 1000 engine. RRSPs have been used in the aero engine sector since the 1980s, but have only become a major feature of the sector in the last decade or so. They constitute a partnership agreement in which a small number of firms, normally at the instigation of one of the leading engine manufacturers, agree to invest in jointly designing, developing and manufacturing a new engine (Herzog, 2010: 205). As part of their investment the partners commit to funding not only their own costs but a proportion of the total costs for research and development associated with the new engine as well as manufacturing and other costs (Herzog 2010, p.206). In return the partners, who are typically large, highly capable suppliers of major engine systems or modules and are often multinational companies in their own right, are entitled to a share of the programme revenues from both engine sales and long term aftermarket returns. As Jon Maplestone of Rolls-Royce explained, „up-front investment in R & D is rewarded with a shared revenue throughout the life cycle (Gardner 2010, p.8). Since the life cycle could be 40 years RRSPs represent a long term commitment for all concerned.

In this instance Mitsubishi s stake amounted to a 7.0 per cent share in the programme. Mitsubishi was to work on the development and production of the combustor and low pressure (LP) turbine modules, at a specially commissioned new facility at Nagoya in Japan. The following month it was announced that another Japanese firm, Kawasaki, had also agreed to join the RRSP for the Trent 1000 engine. Kawasaki, with an 8.5 per cent stake in the partnership was to develop and build the engine s intermediate pressure (IP) compressor. In Kawasaki s case this was the latest in a long line of collaborations with the British engine maker. Kawasaki was a partner in similar RRSPs on three other Trent engines, the Trent 500, Trent 700 and Trent 800. Other international partners soon followed. In October 2004 Rolls-Royce announced that Goodrich Corporation and Hamilton Sundstrand of the US had agreed to join the RRSP (The Engineer 2004), followed soon afterwards by Carlton Forge Works of California. Goodrich Corporation, already a partner on a number of engines in the Trent series, became responsible for the engine control system, while Hamilton Sundstrand was responsible for the gearbox module. Carlton Forge Works, a leader in the production of seamless rolled rings, was to develop titanium forgings for the fan containment system, the finished ring mount that connects the engine to the wing pylon and forgings for the rear fan case. Finally Spain s Industria de Turbo Propulsores SA (ITP), which had been a partner on all five of the previous Trent engines, joined the partnership in mid-2005, becoming responsible for the design, development and manufacture of most of the low pressure (LP) turbine, as well as final assembly of the module. ITP s admission to the partnership brought the total stake of the six partners to 35 per cent (see figure 2).

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Insert Figure 2

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By 2005 General Electric too was well advanced with its plans for its engine for the Boeing 787, the GEnx. Like Rolls-Royce it too relied on using technologies from other engines in its portfolio. The GEnx used much of the technology originally developed for its much larger GE90 engine launched in the 1990s. This included a fan with 18 composite rather than titanium blades originally designed for General Electric s aborted GE36 unducted fan engine and a key feature of the GE90 engine (Norris and Wagner 2009, p. 94) that powers the Boeing 777. Despite being one of the world s largest industrial companies, General Electric like Rolls-Royce, made extensive use of international collaboration to design, develop and manufacture its new engine. It too utilized an RRSP comprising Ishikawajima-Harima Industries and Mitsubishi of Japan, and Fiat Avio of Italy, Sweden s Volvo Aero and Techspace Aero of Belgium (Norris and Wagner 2009, p. 101). Together these five partners had a 36 per cent stake in the RRSP.

With the RRSP established, design and development work on the Trent 1000 engine was soon under way. Teams of engineers from partner companies spent lengthy periods at Rolls-Royce s Derby site, where its large commercial engine division is based. ITP completed the design of the LP turbine in a record time of nine months. The total cost of its share of the programme, covering design, development and manufacture amounted to more than 150 million euros and covered both material and non-material outlay (ITP 2006). Assembly of the first Trent 1000 engine formally commenced at Derby in May 2005. In October of the same year Kawasaki was able to ship the first complete IP compressor module for the Trent 1000 to Derby from its new purpose built facility at Seishin in Japan.

On the 14th February 2006 the Trent 1000 successfully completed its first test-bed run. The first test run engine was one of seven development engines assembled for ground testing. A further nine engines were ear-marked for flight testing. In June the following year the first Trent 1000 engine was delivered to Boeing in Seattle in preparation for the formal roll-out ceremony of the 787 Dreamliner the following month. June 2007 also saw the Trent 1000 take to the air for the first time in Waco, Texas aboard Rolls-Royce s Boeing 747-200 flying test-bed. Two months later in August 2007 the engine received its airworthiness certificate.

Severe hold-ups on the 787 Dreamliner programme however meant there was a lengthy delay between the Trent 1000 being certificated and the engine actually entering service. Not until the 15th December 2009 did the 787 powered by Trent 1000 engines make its first flight and it finally entered scheduled airline service with launch customer All Nippon Airways on the 26th October 2011.

CASE ANALYSIS

The nature of the production network created through the RRSP set up by Rolls-Royce to design, develop and manufacture the Trent 1000 engine (figure 2) becomes evident when one considers that unlike the situation a decade ago, less than a third (30 per cent) of the engine is today manufactured by Rolls-Royce in its production facilities in the UK. In fact the six partners in the RRSP are responsible for a bigger share of the engine amounting to 33 per cent, with the balance procured through the aerospace supply chain. The distribution of work in this way forms part of an overall trend towards externalisation as the engine makers have increasingly outsourced work , described by Brusoni and Prencipe (2001, p.193) in terms of, „increased specialisation of the supplier base, leading to greater division of labour across… the different levels of actors involved in the industry . What is evident from the case study is that through the use of RRSPs like that for the Trent 1000, externalisation on the part of the engine manufacturers has also been accompanied by internationalisation leading to the creation of global production networks.

With all six of the partners in the RRSP based outside the UK, this makes the Trent 1000 engine programme a genuine global production network, where production facilities are spread across three continents: Europe, North America and Asia. This contrasts sharply with earlier large engines produced by Rolls-Royce and its competitors. The RB211 engine for instance, developed in the 1970s by Rolls-Royce for the Lockheed Tristar airliner was produced in its entirety by the company at its production facilities in the UK. Similarly the 524 engine developed for the Boeing 747 in the 1980s utilized a RRSP, but with only two partners, Mitsubishi and Kawasaki, who played relatively minor roles, with stakes that in total came to just eight per cent of the programme (European Commission 1996), compared to 92 per cent for Rolls-Royce.

Nor is it simply production (i.e. the manufacture of components) that has been internationalised in this way. Alun Hughes, Rolls-Royce s Director of Risk and Revenue Sharing notes that the partners, „bring technologies, capabilities, investment and risk sharing, plus highly competitive design and manufacturing ability (Hutchinson 200, p. 2) As the case clearly shows, all six of the partners were involved in the programme from its inception. One of the first steps taken by Rolls-Royce, once it became clear that the Trent 1000 had been chosen as a powerplant for Boeing s new 787 Dreamliner, was the selection of partners in the RRSP. Staff from the partner companies then worked alongside Rolls-Royce staff at Derby particularly in the design and development phases of the programme. In the case of Kawasaki for example, a team of engineers were dispatched to Derby within a short time of the company agreeing to participate in the RRSP.

In this global production network, product development was undertaken on an integrated basis with all six partners working closely with lead firm, Rolls-Royce. With the Trent 1000 engine programme it was not a case of the lead firm undertaking design and development and the overseas partners carrying out manufacturing on what in the aerospace industry is termed a „build-to-print basis. A very significant feature of global production networks involving RRSPs is that the relationship between the junior partners and the lead firm is long term. As Alun Hughes, Director of Risk and Revenue Sharing at Rolls-Royce notes, „Partners are with us for the long term - they don t have to compete every five years to win their right to retain "their" part of the work (Hutchinson 2003, p.3). Having said that, the case study demonstrates very clearly that the RRSP placed Rolls-Royce in the lead role within the programme. It is not just as table 2 makes clear that Rolls-Royce has a very much bigger share of the programme than any of the other partners. Quoting Alun Hughes again, „We drive the programme and our partners have to trust us to do that effectively (Hutchinson 2003, p.3). The ability of engine makers like Rolls-Royce to take the lead in engine projects utilizing RRSPs, helps to explain why in recent years they have tended to replace joint ventures as the preferred form of collaboration and the basis of the global production networks in the aerospace industry. In terms of governance, RRSPs leave the lead firm firmly in control of the programme.

As well as providing insights into the role of RRSPs in global production networks in the aerospace industry, the case study also sheds some light on the drivers that have led to the development of these networks. Three factors stand out . Of these the most apparent is access to capital. Developing a new engine for a modern airliner is a long and expensive process and development costs have exhibited a long term upward trend. This is one of the reasons why engine makers opt if they can for derivative engines that borrow from earlier designs. In the past engine manufacturers have been able to rely on financial support, whether direct or indirect, from governments, in order to help them offset the huge development costs associated with new engine programmes. In the UK this financial support has been direct through the provision of „launch aid , where the government advances money towards development costs and is then repaid out of subsequent revenues. However while earlier Trent engines received launch aid, the Trent 500 for the Airbus A340-600 for instance getting £200 million in 1997 (Harrison 1997), increasingly stringent WTO rules meant that the Trent 1000 programme received none. To compensate, Rolls-Royce utilized more RRSP partners than on previous programmes and between them they invested a bigger share amounting to 35 per cent of the project (table 2). Hence expanding the RRSP from one or two partners on earlier projects to six on the Trent 1000 effectively gave access to additional capital, making up for the lack of launch aid.

In fact some of the partners were themselves able to access financial support from their governments. ITP for example received €35 million from the Centro para el Dessarrollo Technólogi Industrial (CDTI), an agency of the Spanish Ministry of Industry, Commerce and Tourism, for the development of the LP turbine module (European Commission 2008). The Japanese partners, Mitsubishi and Kawasaki, were similarly able to access significant amounts of state aid from the Japanese government (Pritchard MacPherson 2005, p. 10).

A second key factor was market access. At one time the North American market formed the biggest slice of the worldwide market for commercial airliners. But, as traffic has grown rapidly in other parts of the world fuelled by economic development and globalisation, latterly North America has been displaced by the Asia Pacific region (Bowen 2007, p. 315). Consequently the ability to make a commercial airliner attractive to Asia Pacific airlines, was an important imperative for Boeing and engine makers General Electric and Rolls-Royce when marketing the new 787 Dreamliner. One way in which manufacturers have traditionally endeavoured to make their products more attractive is through offset agreements, where a manufacturer agrees to purchase components produced in the country of origin of the prospective customer. More recently global production networks have come to perform a similar function. Over the last decade, the Boeing 777 where Japanese firms account for 20 per cent of production (Sabbagh 1995, p. 190), has sold extremely well in the Asia Pacific region where more than a third (35.8 per cent) of its sales have been achieved (Bowen 2007, p.315).

And so it proved with Rolls-Royce. With the Trent 1000 developed and manufactured through a global production network where a substantial part of the engine was built in Japan, made the engine attractive to buyers from the Asia-Pacific region. As table 3 shows some of the biggest orders for Trent 1000 powered 787s came from airlines based in the Asia-Pacific. It was no coincidence that with the 787 the launch order and the second largest order for 55 aircraft came from All Nippon Airways (table 3) for Trent 1000 powered jets. Nor were they alone, as other Asia-Pacific airlines that opted for Trent 1000 powered aircraft included Air China, Air India and Air New Zealand.

The third factor that has been an important driver behind the increased use of global production networks in the aero engine sector is the move towards a much stronger service orientation on the part of the engine manufacturers. The business model employed by the engine makers is a razor and razor blades model where sales of new engines are typically heavily discounted with profits generated instead from the sale of spares. However this model has come under intense pressure in recent years as modern engines are much more reliable and have a much lower spares requirement. Consequently engine manufacturers have become much more involved in the provisions of repair and maintenance services, particularly through long term agreements such as „power-by-the –hour , where a given level of engine availability is guaranteed. These represent significantly more value added than spares alone.

The focus on services, with engine manufacturers getting a much bigger proportion of their total revenue from services, has led them to focus on those technologies and systems that are critical to engine performance such as the fan and the hot core of the engine. Other systems they have increasingly been willing to outsource to suppliers who themselves have enhanced their core competences. In this they have been helped by the increasingly modular nature of modern engines. This is especially the case with Rolls-Royce s Trent engines which, unlike those produced by the company s American rivals, share a common three shaft layout whose architecture by its very nature is modular.

CONCLUSION

This paper presents a study of global production networks in an industry sector where they have recently become much more important and where they have been largely neglected by researchers. The case that lies at the heart of the study, drawn as it is from a current engine programme linked to one of the most significant commercial aircraft flying today, typifies the global production networks which are now an important feature of the commercial sector of the industry.

The study shows the truly global nature of these production networks, which in many cases design, develop and manufacture on an integrated basis across three continents. Similarly it also highlights the characteristics of the actors that make up these networks. At the centre, the flagship or lead firms comprise the very small number of engine makers with the capacity to manufacture engines of all types. They it is that take overall responsibility for design, manufacture, marketing and product support, and who establish and manage the networks. The other actors are a small number suppliers, who are major undertakings themselves, who typically specialise in the design, develop and manufacture of specific sub-systems and modules.

The trend towards global production networks is quite pronounced in the aerospace industry , particularly the aero engine sector. The drivers behind this are shown to be different from those in many of the other sectors where global production networks have been studied, and comprise , increasing financial pressures , the need for market access and recent changes in strategy by the engine makers, especially re-focusing their portfolios to include a greater emphasis on services.

The case study reveals that the creation of these global production networks relies on a specific form of governance not commonly found in other industry sectors, namely the risk and revenue sharing partnership. This form of governance places the flagship firms in a powerful position in relation to the other actors in the network. However despite the unequal distribution of power, the study shows the relationship is not a transactional one, as is typically the case with buyer-driven networks. Rather both parties work closely together in relationships characterised by trust and reciprocity, because of the demands of new product development using advanced technologies and the long term nature of the collaboration. Thus the study of social capital by multinational firms to leverage competitive advantage in global markets, could provide useful insights into the analysis of global production networks in the capital goods industries.

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Table 1 The Trent Engine programme

Engine	**Trent 500**	**Trent 600**	**Trent 700**	**Trent 800**	**Trent 900**	**Trent 1000**
Thrust lbs	53,000-56,000	65,000-68,000	67,000-71,000	92,000-95,000	80,000	58,000-70,000
Fan size	97.5 in.	95 in.	97.5 in.	110 in.	116 in.	112 in.
Bpr	8.5:1	8:1	5.5:1	6.5:1	8:1	11:1
Entry into service	2002	Withdrawn	1995	1996	2007	2011
Application	A340	MD11	A330	B777	A380	B787
GE *P & W*	CFM56	---	CF6 PW4000	GE90 PW4080	GP7200 GP7200	GEnx

Source: Harvey (1990: pp2-5); Walters (1999: pp115-118); Wastnage (2004: p6)

Table 2

Partners in the Trent 1000 engine programme

Partner	**Country**	**Share**	**System/components**
Rolls-Royce	UK	65.0%	Systems integration
Kawasaki Heavy Industries (KHI)	Japan	8.5%	Intermediate pressure compressor
Mitsubishi Heavy Industries (MHI)	Japan	7.0%	Combustor & LP turbine blades
Goodrich	US	n/a	Engine control system
Carlton Forge Works	US	n/a	Fan containment system
Hamilton Sundstrand	US	n/a	Gearbox
Industria de Turbopropulsore (ITP)	Spain	12.0%	Low pressure turbine

Source: Norris and Wagner (2009).

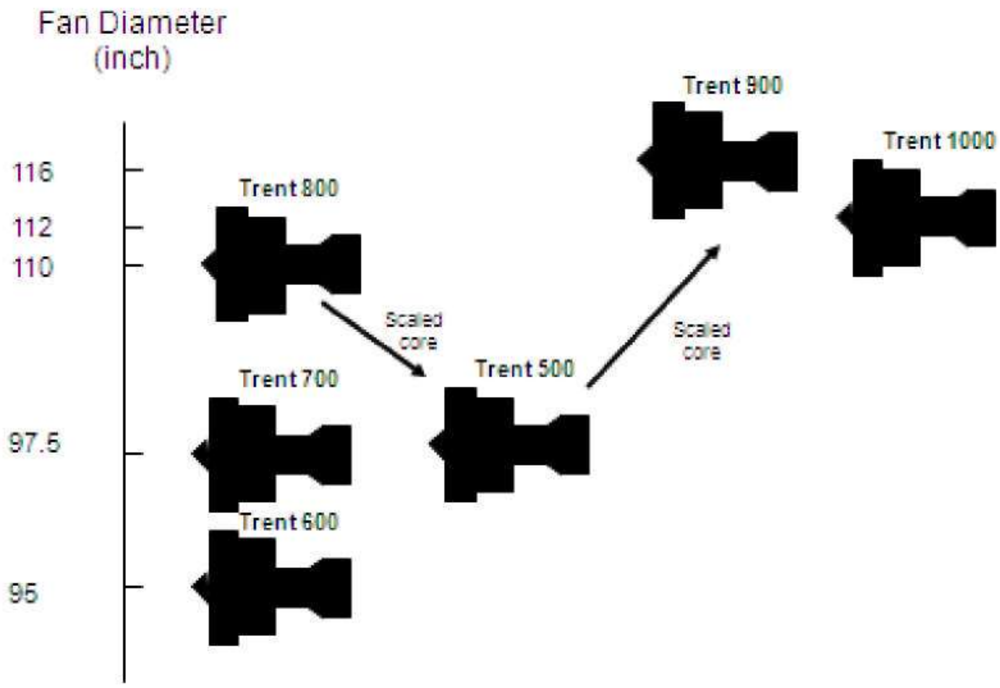
Table 3
Boeing Dreamliner 787 Orders

Airline	Orders	GE	RR		Airline	Orders	GE	RR
Aeroflot	**22**	-	-		Icelandair	1	-	1
Aeromexico	2	2	-		ILFC	79	7	9
Air Berlin	15	-	-		Japan Airlines	35	35	-
Air Canada	37	37	-		Jet Airways	10	-	-
Air China	15	-	15		Kenya Airways	9	-	-
Air Ethiopia	8	-	8		Korean Air	10	10	-
Air India	27	-	27		LAN Airlines	26	-	26
Air New Zealand	8	-	8		LCAL	5	-	5
Air Niugini	1	-	1		LOT Polish Airways	8	-	8
ALAFCO	14	14	-		Nakash	2	-	2
ANA	55	-	55		Naruga Air Shuttle	3	-	3
Arik Air	7	7	-		Privat Air	2	-	-
Arkia	2	-	-		Quantas	50	50	-
Avianca	12	-	12		Qatar Airways	30	30	-
Aviation Capital	5	-	-		Republic of Iraq	10	-	-
AWAS	??				Royal Air Maroc	4	4	-
Azerbijan Airlines	2	2	-		Royal Jordanian	7	7	-
Birmin Bangladesh	4	-	-		Saudi Arabian Air.	8	-	-
British Airways	24	-	24		Singapore Airlines	20	-	-
Business jet/VIPs	6	2	-		Travel Service	1	-	-
China Southern	10	10	-		TUI Tavel	13	13	-
CIT Leasing	10	10	-		Unidentified	16	-	1
Continental Air.	39	39	-		United Airlines	25	-	-
Delta Airlines	18	-	18		Uzbekistan Airways	2	2	-
Ethiopian Airlines	10	10	-		VALC	8	-	-
Etihad Airways	31	31	-		Vietnam Airlines	8	-	-
Gulf Air	16	-	-		Virgin Atlantic	15		15
Hainan Airlines	10	1-	-		Total	797	337	212

Source: Boeing

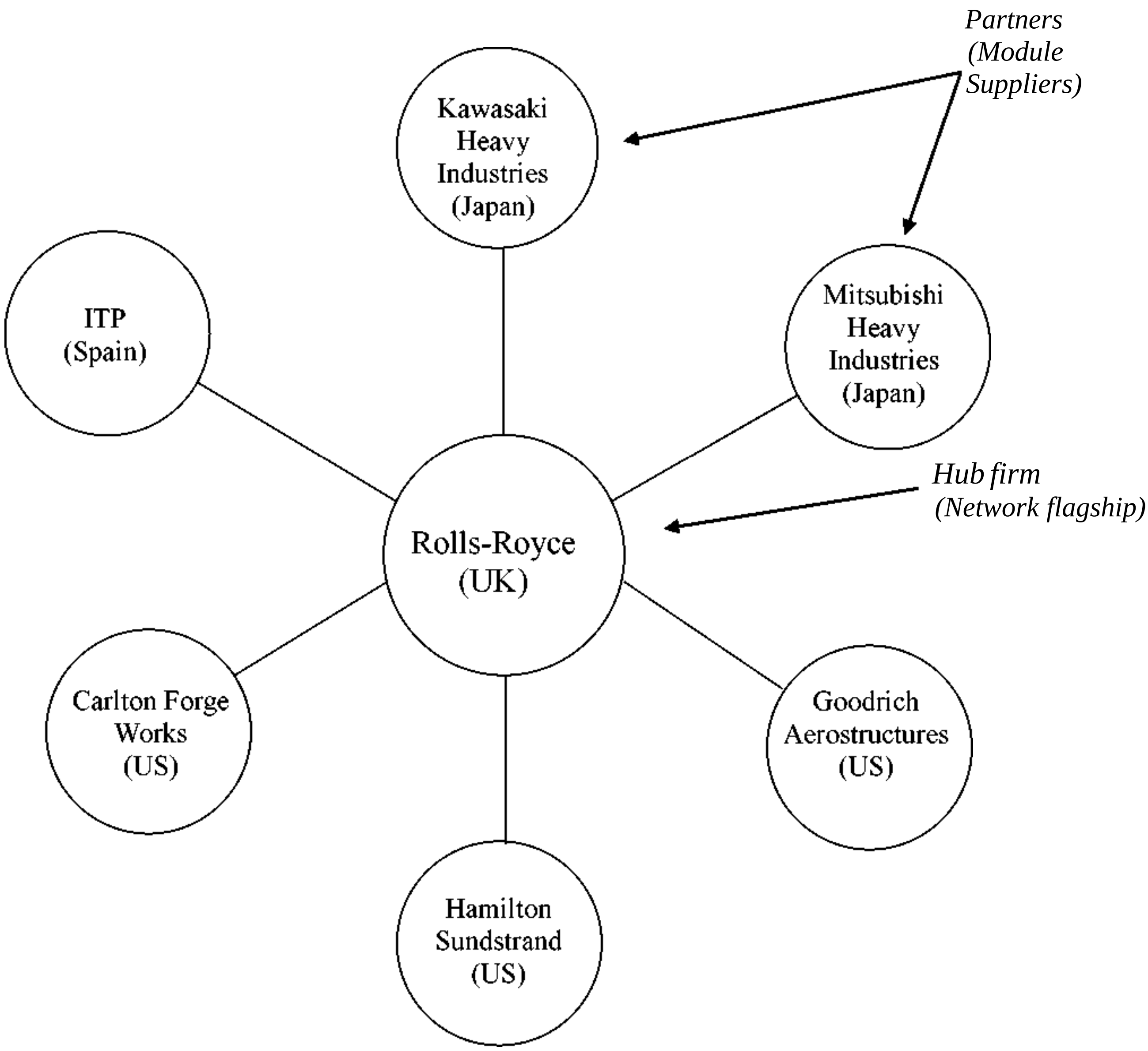
Figure 1

Trent engine family



Source: Burchell, B. (1999)

Figure 2
Global Production Network: Trent 1000 programme



Source: Norris and Wagner (2009)