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DRUID 2013 Submission_ Sectoral Systems of Learning in Late Industrialising Nations ? A study of the Chinese Civil Aviation Industry

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Abstract

China?s 11th five-year plan in 2006 signalled a shift towards innovation-driven economic growth and the development of the civilian aircraft industry identified as a key strategic project. This involves a steep learning curve which is currently not well supported by China?s national innovation system; much of the learning arises out of China?s participation in the global aviation supply chain. Whilst this chain itself is highly innovative China?s contribution does not yet include any innovative novelty. To analyse China?s progress I synthesize three frameworks on systems of technical change: national and sectoral systems of innovation and national systems of learning. The paper offers novelty in the complementary application of these frameworks to provide an analysis of progress in China?s civil aviation industry.

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China's 11th five-year plan in 2006 signalled a shift towards innovation-driven economic growth and the development of the civilian aircraft industry identified as a key strategic project. This involves a steep learning curve which is currently not well supported by China's national innovation system; much of the learning arises out of China's participation in the global aviation supply chain. Whilst this chain itself is highly innovative China's contribution does not yet include any innovative novelty. To analyse China's progress I synthesize three frameworks on systems of technical change: national and sectoral systems of innovation and national systems of learning. The paper offers novelty in the complementary application of these frameworks to provide an analysis of progress in China's civil aviation industry.

1. Introduction

Over the past 30 years China has become one of the world's largest economies based on its manufacturing capabilities and low-cost production. However, China is determined to shift towards innovation-driven growth. Within the 11th five-year plan (2006-11), the civilian aircraft industry was identified as a key strategic project in this ambition. The aim seems timely with predictions of global demand for civil aircraft exceeding 34,000 new planes by 2031 and China alone requiring about 5,200 planes. (Boeing, 2013). Given Boeing and Airbus are unlikely to meet this demand, room for a third provider seems feasible. However, China faces a steep learning curve given its history of failures.

This paper provides an assessment of how far China's learning in civil aviation has progressed, how it has developed competencies to be active in the manufacturing of civilian aircraft to date, and what might be improved to enhance their chances of success of building their own aircraft. The paper combines 3 normally mutually exclusive frameworks to conduct the analysis: the national and sectoral systems of innovation and the national system of learning.

2. Literature Review

2.1 National systems of innovation (NSI)

Through the work of Freeman (1987), Lundvall (1988), Nelson (1993) and others, the NSI has become understood as the interaction of science, technology and innovation (STI) through the activities of governments, university/research institutes and firms. Equally important but often overlooked (Lundvall 2007), are the doing, using, interacting (DUI) elements of the NSI.

China's modern interest in developing an indigenous aviation industry capable of building aircraft to international standards stems from its ambition to become an innovation driven economy. As such it appears obvious to utilise the national system of innovation (NSI) as an analytical framework. Indeed Gu and Lundvall (2006) and Liu & White (2001), Tang and Hussler (2011) amongst others have applied the NSI to China but all found that the DUI aspects were weak and impeded its ability to fully utilise its STI foundations. As such, its usage here as the key analytical framework is somewhat unsatisfactory.

2.2 Sectoral systems of innovation (SSI)

The global aviation industry underwent phenomenal changes in the latter part of the 20th century with creation of Airbus and the consolidation and rationalisation of OEM and component manufacturers in the United States and Europe. It is now a truly global industry and a global sectoral innovation system.

The SSI framework (Malerba 2002a, 2002b; Malerba 2004) has been employed in the analysis of several different sectors including aerospace (Hollanders et al., 2008) and in developed nations and developing nations (Malerba and Mani 2009), for example the Chinese automotive industry (Liang, et al. 2009).

Malerba (2002b) indicates that SSI's are not necessarily bounded by national borders for knowledge interaction, although national boundaries for some key institutions and local boundaries for the labour market may coexist in a sectoral system. Malerba proposes three building blocks which are adopted here: i) actors and networks, ii) knowledge and technology and iii) institutions. However, the SSI with its emphasis on ‘the creation, development and diffusion of *new* sectoral products’ is based on ‘innovation’ (as is NSI to be fair) and aviation experts do not consider China be making innovative contributions. Hence, due to the lack of innovation, the sectoral innovation system approach in its entirety was also deemed unsatisfactory as the sole analytical framework.

2.3 National learning system (NLS)

Prior to 1949, like most others, China had no indigenous capability in aircraft production, however unlike others, by 1978 there was still relatively little demand for them. Given their Advance Regional Jet for the 21st Century (ARJ21) programme was only officially sanctioned in 2001, despite production delays and current difficulties with safety certification, if China start meeting their on-book orders, China would undoubtedly consider this an innovation success story however, others would not. The latter would acknowledge it as China’s progression along its learning curve. Thus given the lack of real innovation in China’s aviation progress, Viotti’s (2002) concept of the National Learning System has appeal for this study.

2.3. National Learning Systems (NLS)

Viotti (2002, p.658) writes ‘learning is the absorption of already-existing techniques’ and that learning drives late industrialising countries, with innovation (strictu sensu) being ascribed to advanced nations. Viotti identifies ‘production’, ‘improvement’ and ‘innovative capabilities’ as three separate capabilities associated with ‘absorption’, ‘incremental innovation’ and ‘innovation’ (strictu sensu). For Viotti, incremental innovation is the ‘generation of improvements in the vicinity of acquired techniques’ whereas innovation (strictu sensu) has a large component of creativity. Viotti then relates these activities to learning strategies. The activity of ‘knowledge absorption’ is associated with a ‘passive learning strategy’ – i.e. learning by doing with the aim of just replication. The activity of ‘incremental innovation’ is more complex; it can arise from passive learning which leads to some minor improvement or it can be ‘active learning’ which requires a conscious commitment of effort to technological accumulation which then leads to minor improvements. The activity of ‘innovation’ (strictu sensu) is distinct in that it builds upon the combination of prior accumulated knowledge which is employed creatively to generate novel outputs.

Viotti argues that the prevailing learning strategy at country level depends on the national system of technical change in which its firms are embedded and that nation can engage in active (rather than passive) learning strategies under 'appropriate external institutional conditions' (Viotti, 2002, p 665). Thus national institutions are key. But when dealing with a highly globalised sector, institutional influences from many nations may be brought to bear or even sectorally specific institutions which arise as norms or practice within a particular industrial setting. Thus the direct employment of Viotti's NLS in its entirety is also inappropriate to analyse China's progress in civil aviation.

3. Synthesising three systems of technical change

Academic authors have combined different systems of innovation frameworks previously (Fromhold-Eisebith (2007), Leo et al. (2007), Malerba (2002)). Here, given the complex systems nature of aircraft (Davies & Hobday 2005; Hobday et al, 2000; Prencipe, 2000), the rationale for combining NSI, SSI and NLS is as follows. The strengths of the SSI are that it allows for actors to come from a range of sub-sectors, from across national boundaries, hence the knowledge flows and institutional influences the sector works with, and under are multinational. Whilst the SSI seeks to comprehend knowledge creation, diffusion and absorption, the NSI offers insights into the 'modes' of these processes through its DUI aspect. The NLS then allows us to understand how the DUI aspects lead to the development of learning strategies that are employed to develop a range of capabilities.

By looking at the knowledge exchange between Chinese and foreign actors through the DUI processes we can discern the learning strategies used to facilitate the development of Chinese aviation technology capabilities. Whilst Chinese actors work predominantly within their national institutional framework their sectoral affliation also subjects them to international influences. This fusion of institutional frameworks exists (at least in part) to support the technological learning strategies Chinese firms and encourages them to move from passive to active strategies of learning, and from absorption to incremental innovation.

4. The Chinese civil aviation industry

China is shifting towards a more innovation-driven orientation having relied upon its manufacturing capabilities and low-cost production in the past. The civilian aircraft industry was identified as a key strategic project area, especially giant aircraft. Given the steep learning curve China faces in this objective, it is prudent to offer a historical account of its activities in this sector. I consider three phases:

The pre-1979 period provides useful insights into the Chinese civil aviation industry as the main actors and institutions in the current era were roots were set in place then.

1970-2005 signals China's 'open door policy' when market access was offered to foreign firms in exchange for technologies and China became an attractive location for inward foreign direct investment and outsourced activity. China's membership of the WTO in December 2001 enhanced its attractiveness still further. As a consequence, capabilities have been transferred to China leading to degrees of competence building in specific components by the Chinese, but the transfers have been more limited than China had hoped for. The period also saw a restructuring of China's NSI which led to the growth of indigenous champions more broadly in some sectors but not aviation, although their regional jet programme was initiated.

2006 begins the 11th Five Year Plan (2006-10) and China's determination to achieve innovation-led economic growth through more indigenous efforts. In addition to the regional jet programme, China embarks on a narrow-body jet programme that could potentially establish it as a rival to Boeing and Airbus.

4.1 Pre 1979

4.1.1 Actors

Under the planned system, manufacturing enterprises and R&D centres were separated but coordinated by sector specific ministries and bureaus. R&D units conducted reverse engineering on imported technology and evolved into specialized categories: the Chinese Academy of Sciences (responsible for basic research), universities (responsible for training and research) and industry-specific institutes (responsible for applied problem solving and technology introduction to the manufacturers) (Liu and White, 2001).

Prior to 1949, China like most other countries had no indigenous capability. When the People's Republic of China was formed in 1949 it established a Central Military Commission (CMC) which controlled the Aviation Bureau. Through the 1950's and '60's a series of ministries were responsible for the aviation, defence and aeronautics industries and perceived them to be solely military assets. By 1972 the Ministry of Aviation Industries (MAI) was under the remit of the civilian sounding State Council, but its focus was still military aircraft. In 1978 domestic civil aircraft only accounted for 6.5% of total aviation production (Dougan 2002), and these were used to support primary industries (crop-spraying etc) rather than commuter traffic or tourism.

The MAI consisted of several bureaus with functional specialisms and responsibilities for specific factories e.g. the aircraft bureau was responsible for military and civil aircraft frames, engine bureau for engines, etc. Additionally, there were bureaus with horizontal responsibilities e.g. the production scheduling across the functional bureaus. The State Planning Commission drew up planning schedules and production targets for MAI and ensured supplier industries fed input to MAI. The Ministry of Education oversaw training and the State Science and Technology Commission regulated S&T activities across both R&D institutes and manufacturing enterprises (Liu and White 2001). Factories were just production units at the bottom of this structure. Each bureau and factory was responsible for executing the 'plan'.

The key foreign actors were the military agencies of the USSR, who provided aircraft, some training for their maintenance, and technology associated with the production of simple piston and jet engines.

'Demand' for aircraft also came from the Chinese government. Mostly it was for surveillance, military use and for general-purpose civilian aircraft e.g. agricultural purposes. The Civil Aviation Administration of China's (CAAC) central office made expenditure decisions on both domestic and foreign aircraft purchases within the Five year plans. They coordinated with the MAI who supplied the required aircraft. However, often foreign purchases of civilian aircraft formed part of larger international relationship building efforts[1] so the CAAC did not have total control over its own 'demand' for aircraft.

4.1.2 Knowledge and technology

Despite production being focussed on military aircraft, aircraft were not actually of military significance. China preferred to focus on nuclear deterrents and missile development (Sweeney 2008). In 1950 there were only around 200 combat planes in total (Zhang, 2002) all Soviet imports. In principle China's aviation industry aimed to evolve from repairs, to reproduction, to independent design and manufacture. Indeed China serviced Soviet aircraft during the Korean War, conducted repair work during 1951-53 and was able to duplicate simplistic aircraft trainers from Soviet models and their piston engine by 1954. Two years later with Soviet assistance, the J-5 fighter was manufactured in China and the capabilities to produce basic jet engines acquired. By 1958 China had designed and manufactured its first indigenous jet aircraft (although strongly modelled on a Soviet equivalent). But in 1960, the Chinese-Soviet relationship broke down and China's projects abandoned. China's political isolation meant their basic indigenous technological levels remained stagnant for another two decades.

4.1.3 Institutions

When the PRC was proclaimed on October 1, 1949 the national institutionalisation of modern science and technology occurred, again modelled on the USSR's (Gu and Lundvall 2006, p.16).

The norm for coordinating resources was via the production bureaus that created coordinative linkages between factories, the MAI that created the linkages between the different bureaus, and the State Planning Commission that created linkages between industries. In each case the linkages consisted entirely of input requirements and production targets. Among factories, individualism was not encouraged. Incentives to raise their profiles through improved quality, new ideas, efficiency gains in production costs based on experience and local conditions (all of which would have indicated innovative activity) did not exist. The protection of intellectual property also

[1] E.g. Purchases of Soviet civilian aircraft in the early 1950's and Boeing 707's and 747's in the 1970's were political relations building gestures.

did not feature at this time. Nevertheless, China's experiences in this era allowed them to develop competences to interpret basic design and engineering technologies in aircraft production through replicative and imitative behaviour.

4.1.4 DUI, learning strategies and capability building

It is clear that China was 'doing' low level maintenance and 'using' existing Russian technology to replicate simplistic training models or basic engines. Learning strategies were confined predominantly to passive learning which enabled the Chinese to absorb this basic knowledge, or at best, almost incidentally make incremental innovations. Whilst reverse engineering was a deliberate attempt to undertake active learning for innovation (strictu sensu) given final aircraft strongly resembled Soviet models suggests the outcome was only incremental innovation.

When the relationship with the USSR ruptured in 1960 many Chinese projects had to be abandoned and for the remainder, China had to quickly develop indigenous sources of supply and related capabilities[2]. However, the organisational chaos of the Cultural Revolution limited China's capabilities to replication and imitation. Meanwhile, the global aircraft industry continued to progress especially in the areas of airframe design and aero-engine manufacturing and China's complete political isolation meant it was unable to keep pace (ibid). By 1976 experts from the West concluded that China's capabilities in military technology and armaments were 20-30 years behind that of advanced industrialised nations (Nolan 2001).

4.2 1979-2000

4.2.1 Actors

4.2.1.1 Chinese governance on the supply side

China needed import aircraft, so the China Aviation Technology Import/Export Corporation (CATIC) was established, given control over developments in foreign trade and access to foreign technology and assets, and granted financial and administrative independence from the MAI (Dougan 2002).

[2] Again one is struck by China's resourcefulness and ability to learn. Dougan (2002, p 49) reports that only 20% of the 12,319 parts used in the J-6 fighter jet and the 9,019 parts in the Zhi 6 helicopter were sourced domestically from China in 1960, by 1965 100% was sourced domestically.

The MAI continued to be responsible for the aviation industry until 1993, when Aviation Industries of China (AVIC) was established as a ‘corporation’ with the remit to focus more on civilian production. In 1999 AVIC was split into two AVIC I and AVIC II. AVIC I with relatively more civilian pursuits including the regional jet programme and AVIC II with relatively more military pursuits including helicopters and cargo transport (but also responsibility for the JV with Embraer in 2002 for the assembly of ERJ145 50-seat jets). In reality both had roughly duplicate responsibilities leading to two weak organisations both with insufficient resources, scale and productivity (Nolan, 2001; Sweeney, 2008). Ironically, this restructuring coincided with the phenomenon of mergers and consolidation at the global level which has left us with the duopolies of Boeing and Airbus in the wide bodied jet and Bombardier and Embraer in the regional jet segment.

AVIC in 2002 was a very complex organisation (see Figure 1 above) with more than 200 enterprises, 36 scientific research institutes, seven national laboratories and two graduate schools (Dougan 2002). However, only eighteen were actually core to aviation manufacturing. The others were in any other activity that provided short-term profit (Nolan and Zhang 2002).

4.2.1.2 Chinese governance on the demand side - domestic airlines

On the demand side the main actors were the domestic Chinese airlines as few foreign lessors or airlines bought Chinese aircraft. The airline industry in China effectively experienced marketization during the 1980’s and 1990s. In 1985, six regional bureaus under CAAC’s control were re-established as air transport SOEs each of which formed their own airline companies by 1991 (See Table 1).

These plus four other companies created by CAAC were under CAAC’s direct control and accounted for 82 % of commercial passenger, and 87% of commercial freight, traffic respectively in the early 2000’s (Dougan, 2002, p. 162). The government further encouraged affiliates of CAAC with the establishment of another group of airlines by local governments through joint ventures with the six regional bureaus. A third group of airlines was established by provincial and municipal governments either with other large central government organisations, or independently; these airlines were independent of CAAC (Dougan, 2002). It is believed that the airlines did not have to pay for the older Chinese aircraft in their fleets (e.g. the Yun-series and turboprop aircraft) as these were produced and allocated within the larger 'Plans' and in reality, some of these airlines only had one or two aircraft in their 'fleet'. However, China's airlines became reliant on international imports from Boeing and Airbus although even by 1998, China's entire commercial aircraft fleet only consisted of 510 aircraft when in the USA, a typical carrier may have had more than 500 craft alone (Keck 2001).

The emergence of so many airlines was made possible by finance leasing arrangements with companies from outside China. Chinese airline companies have also gone through destatization whereby 30% of their value in some cases, were offered as shares in foreign stock exchanges (Dougan, 2002 p178-9). As such the airlines *appear* to have experienced a growing degree of independence from the State. However, the payment of the leases was administrated via CAAC (Sholem 1993) with collateral provided from the Bank of China (Dougan 2002) and the CAAC has never failed to pay. Also, even in the early 2000's CAAC often appointed upper management staff in the dependent airlines from their own staff and with 60% share ownership CAAC still had commercial control (Dougan 2002).

Nevertheless, the airlines adopted more Western styles of management including accountability and profit oriented ambitions. CAAC had to factor the existence of partial foreign ownership into their policy decisions. The airlines could no longer be commanded to do the Party's will through authoritarian control (although softer incentives are still offered to the airlines by CAAC in the attempt to 'persuade' their behaviours into line with policy objectives).

4.2.1.3 Chinese universities

Within China, Motohashi (2008) has found that firm-university collaboration on patents has been increasing, while that with public research institutions has been slowing down. Little appears to be written about the role of universities in the development of China's civil aviation industry although 'in 2004 39% of Aerospace Engineering authors were from China although remarkably lower in the case of the Journal of Aerospace Engineering' (Goldstein, 2007, p272, footnote 8). Additionally, Williams (2009, p.196) notes that 'the high technology aspects of airspace management are now the subject of very active research agendas for a number of leading scientific institutions in China' such as Tsinghua University. It seems China's universities are making incremental scientific advances in aerospace although with little impact on the world.

4.2.1.4 Foreign presence and influence

In addition to the import of completed aircraft from the USA and Europe, the presence of foreign aircraft and aircraft component manufacturers becomes more influential during 1979-2000. Early entrants were predominantly American with Boeing being amongst the first to subcontract work out to China in 1979 in the form of doors and wing panel production, others include McDonnell-Douglas, GE and Honeywell. This obviously necessitated transfers of knowledge which the next section will specifically elaborate upon.

4.2.2 Knowledge & technology

4.2.2.1 Indigenous projects

Early efforts (i.e. Yun series 5 to 12) relied on turboprop technology gained by reverse engineering Soviet models in the 1950's and '60's. In the 1980's the Y-10 was an attempt reverse engineer the Boeing 707 including a Rolls-Royce turbofan engine, however the act of reverse engineering that helped China imitate earlier Soviet models was insufficient to garner the technological competence required to do this masterfully. Only the most recent of these models, the Yun 12, received US Federal Aviation Administration certification for airworthiness effectively signalling its quality and safety to international purchasers. However, it had a poor safety record and even those that were reluctantly used by Chinese airlines were taken out of service in 2001.

In the mid 1980's the Ministry of Aviation attempted to establish a 'three step take–off plan' to build a 180-seat aircraft in its Shanghai factories by 2010 via learning from foreign partners like Boeing and McDonnell Douglas in the MD-80 assembly project (Vertesy & Szirmai, 2010) but the project never really gained momentum although it was influential for the ARJ21's design.

In 2000 the MA-60 (or Xinzhou 60 as it is known in China) was launched, a 56-60 turboprop with an extended fuselage, lighter frame and longer range and costing two-thirds that of Western counterparts, yet strong competition in this segment, the technological shift away from turboprops to high speed trains or jet-engine alternatives made this product also a failure (Nolan and Zhang 2003) although a very small number were exported to the Third World e.g. Zimbabwe and Laos (Teslik 2007a).

4.2.2.1.1 The Advanced Regional Jet for the 21st century (ARJ21)

China is now developing the ARJ21 in conjunction with international suppliers. It was both an economic market-demand led response and a political response to the recognition of growing inequalities between the eastern coastal provinces and the western inland provinces. Due to China's economic performance, a growing proportion of the domestic population wanted to travel and engage in domestic tourism. China was also becoming a popular tourist destination for the global traveller (especially with the 2008 Olympics on the horizon) and with large distances between sites, regional aircraft were required. The political response was an attempt to placate growing discord about the unequal regional economic development between eastern and western provinces, so regional airports were invested in to create the infrastructure in which goods and services could be sent to the western provinces and so make those regions more attractive for business investment (Williams, 2009).

On 7 November, 2000 AVIC I officially launched a US$700m project by setting up the New Regional Jet Programme Management Company (as a subsidiary of AVIC I). This parent company had six companies within its consortium (Table 2) and was responsible for defining airframe configuration; defining and subcontracting work-shares; schedules and quality control; final assembly, certification, marketing and customer support. This was named in 2001 as the ARJ21 project, a 70-90 seat passenger aircraft with twin turbofan design, rear-mounted engines and a T-tail with a range of 1,200-2000 nautical miles (JAWA2002-3). Whilst not an exact copy, the ARJ21 is clearly based on McDonnell Douglas MD-82 which was built at the same Shanghai factory in the 1980s and 1990s and despite being labelled a Chinese aircraft a substantial proportion of its more sophisticated components and systems were purchased from global tier 1 and 2 suppliers (Figure 2).

By 2003, its first orders were received all from Chinese airlines or leasing companies. China expects at least 350 domestic sales and 150 exports over 20 years (JAWA 2004-5).

4.2.2.2 Knowledge inflows from the global supply chain

Nascent relationships with a range of international aerospace companies introduced China into the global supply chain for civil aviation in this period and were accelerated and deepened by China's accession to the WTO in December 2001 which has put pressure on China to ease off the use of its 'market access for technology' stance. China has become a subcontractor for a vast array of parts: doors, wing section, turbine disks, blades, bores, rings, atmosphere instruments, meteorological radar, general radar instruments, pumps and valves (Nolan and Zhang, 2002, p. 43). Earlier subcontract work for McDonnell-Douglas in the mid 1980's and 1990's transferred much needed competencies (Goldstein, 2007) whilst the engine manufacturers GE, Pratt and Whitney, Rolls Royce all continue to do small scale subcontracting work in China (Teslik 2007a). In this period, Airbus establishes a number of agreements for Chinese participation: the development of its A318 programme, work on doors and fin fairings for a number of models and wing components for the A320 (Nolan and Zhang, 2002). Embraer and Bombardier both established production facilities to boost their regional jet sales and to defend against the ARJ21 (The Economist, 08/02/07) although Goldstein (2007) suggests that these commitments have not resulted in less inhibited access to the domestic market to the extent hoped for.

The foreign player with the longest relationship with China is Boeing. As mentioned earlier, Boeing outsourced production of doors and wing panels to China in 1979 (Teslik 2007a) but over time, provision has extended to include other components (which will be detailed in the 2000-05 period) (The Economist, 08/02/07; Teslik 2007b). In addition to outsourcing production of aircraft body parts, Boeing has worked with China on industrial production, technical training for aircraft maintenance, pilot and support staff training. It also assists Chinese airlines and airport networks by providing training and technical assistance one key area of which is air traffic management (Jenkins 2003; Teslik, 2007b). Whilst Boeing takes pride in the longevity of its relationship with China, it is noticeable that the components China produces for it are predominantly parts of the body structure rather than any more technologically advanced elements. Similarly, whilst training for complementary aspects of maintenance etc., have been provided, this is mostly self-serving to ensure Boeing has resources in China to service its own planes, maintain its record in flight safety with pilots properly trained to fly Boeing aircraft, or that its planes in the service of various airlines are able to smoothly enter landing slots etc. The same pattern of partnership scope is demonstrated by Airbus although of course in a more condensed time frame (http://www.airbus.com/company/worldwide-presence/airbus-in-china/).

4.2.3 Institutions

When China's 'doors opened' many reforms were implemented to decentralise decision making in both resource allocation (capital and labour) and operations (Liu and White 2001) accompanied by 'legitimate (economic) criterion for evaluating performance' (ibid p 1099). These reforms targeted industrial enterprises in the early 1980s and the science and technology bases in the mid-1980s although most of the initiatives in this period[3] consisted of 'adapative policy evolving through trial and error' (Gu and Lundvall, 2006). It was also the period when China established an intellectual property system that broadly conformed to international standards via its signature to various treaties.

4.2.3.1 Education & the university sector

The two most significant changes here at the national level were the provision of large educational and basic R&D[4] funds to encourage graduates and post-graduates into the areas of science, engineering and management and the encouragement of university spin-off activity via the TORCH Programme in 1988. Whilst technical graduate numbers have increased significantly the salaries of scientists and engineers in the aerospace industry remain low relative to those in other industries, so these graduates are not feeding into the labour force in the scientific and engineering areas. Similarly, there has been phenomenal growth in university spin offs – 42, 945 during 1997-2004

[3] This period is often called the 'transition period' although it is not clear that China has finished transitioning even today.

[4] Whilst the absolute level of funding for basic R&D increased, in relative terms it remained stable at about 5% of total R&D expenditure between 1995-2005 (Liu and Lundin, 2007).

(Hu and Mathews 2008)[5] but no university spin offs relating to the aerospace sector appear to have emerged.

4.2.3.2 Applied R&D

Here the government reduced direct funding to research institutes to create incentives for them to approach industrial enterprises for funding. Further incentives were provided to encourage enterprises to establish in-house R&D and should have been the basis for the creation of absorptive capacity which would allow enterprises to engage in fruitful exchanges with research institutes. Unfortunately whilst in-house R&D expenditure by industrial enterprises rose, the outputs from this expenditure did not rise correspondingly. Instead industrial enterprises increasingly subcontracted out R&D activities to research institutes (Motohashi and Yun 2007) and focused more on the implementation issues of the received research outcomes. Where interdependent relationships were created, the tendency was to focus on short-term projects with immediately deliverable outcomes, as a result many innovations were highly incremental. This suggests that Chinese enterprises were not able to develop sufficiently deep absorptive capabilities at this time.

4.2.3.3 The establishment of an intellectual property regime

China established its modern intellectual property system in 1984 when the first modern patent law was adopted, the same year in which China signed to the Paris Convention on the Protection of Industrial Property. Several rounds of substantial revisions brought China's patent law broadly in line with international standards, when China's entered the WTO in 2001. However a difference remained in that applications needed to fulfill three criteria: novelty, inventiveness and practical applicability or usefulness. 'Practical applicability' means that the innovation can be made or used in some industries and can produce effective results. It is broader in meaning than the term 'industrial applicability' adopted in other countries. The requirement was deliberately constructed to encourage incremental inventive

[5] Notable spin off successes are Legend (now Lenovo) in IT, Huawei in telecommunications, Datang Corporation in power systems and Shenyang Sunshine Pharmaceutical Co. Ltd in biotechnology (Gu and Lundvall, 2006; Liu and Lundin, 2007, Lu, 1997). It is these privatised, university spin-off enterprises which have accounted for much of the growth in China's patenting activity in recent years (Hu and Mathews 2008).

activities for developing the national economy and its breadth enables more inventions and utility models to qualify for a patent (Fai 2005).

4.2.4 DUI, learning strategies and capabilities

By the end of the 1990s the government had relinquished much power over the decision making over technologies, production and outputs, created incentives for the closer integration of R&D production and innovation between different agents, and established markets for technology and products which were entitled to legal protection under intellectual property law, yet there were still problems with China's innovative capabilities. In terms of relating this to the NSI, physically the STI elements and their relationships were formally redefined. The science base had improved in terms of raising the number of graduates and post graduates in science, engineering and technology fields. Universities were encouraged to do more basic R&D via a generous increase in the provision of funds. The context for technological improvement had improved with the changes in funding structure for applied R&D in both industry research institutes and enterprises but the innovative capabilities of China remained weak, although progressing marginally in terms of re-inventing or improving upon existing designs.

The lack of innovation inevitably relates to the DUI aspects of the NSI. There were small amounts of doing, using and interacting which enabled incremental change. However, the inherited institutional practices from the planned economy era remained strong and it appears many organisations, especially state-owned enterprises (SOEs) simply did not know how to react to or engage with the incentives put in front of them. Autonomous decision-making about resources, methods, aims, objectives, outputs, utility etc., were alien skills. Large firms in particular were complacent with respect to investing in innovation (Guan, Yam et al., 2009); continued easy access to state funds meant SOEs interpretation of technological progression was to buy newer capital from overseas (Duanmu and Fai, 2007).

Nevertheless, there was considerable and growing DUI between Chinese enterprises and foreign aerospace companies. It is these relationships that are enabling domestic enterprises to develop not just production capabilities through passive learning, but also incremental innovation and improvement capabilities through both passive and active learning.

4.3 2006-present day

2006 marks the 11th five year programme in which China announces a significant move to become an innovation-oriented economy with emphasis on independent innovation. The science and technology development programme identified eight cutting edge technology areas including aerospace and 16 special research projects including 'R&D of giant planes' and (Wilsdon & Keeley, 2007). Evidence of China's ambition comes in the form of the continued progress of the ARJ21 project and the launch of the C919 jetliner programme.

4.3.1 Actors

The restructuring of the sector saw China demonstrate efficiency gains in the manufacturing and repair of aircraft, much of it through the rationalisation of labour (Williams, 2009), and a rapid increase in the value added by its aircraft industry from US$1.1bn in 1995 to US$3.3bn in 2006 (Hollanders, et al. 2008, p.14). In particular, the key actors AVIC I and AVIC II underwent considerable restructuring. Having been established in 1993 then split in 1999, in November 2008, AVIC I & II re-merged to form AVIC (Figure 3). The government then organised AVIC into 6 businesses (5 civilian, 1 defence) in 2009 with the future intention of spinning them off as independent stock market listed companies (See Table 3).

In May 2008 the Chinese government also inaugurated China's first ever jumbo passenger aircraft company, Commercial Aircraft Corporation of China Ltd (formerly CACC/ACAC but now commonly known as COMAC)[6] (See Figure 3). This is responsible for researching, developing, manufacturing and marketing home-grown passenger aircraft. It was given responsibility for continuing with the ARJ21

[6] A state-owned company, jointly invested in by the State-owned Assets Supervision and Administration Commission (SASAC) of the State Council, Shanghai Guosheng (Group) Co., Ltd., Aviation Industry Corporation of China (AVIC), China Aluminum Corporation (CHINALCO), Baosteel Group, and Sinochem Group. It is headquartered in Shanghai and comprises of six member organizations: COMAC Commercial Aircraft Co., Ltd. (ACAC), Shanghai Aircraft Design and Research Institute (SADRI), Shanghai Aircraft Manufacturing Co., Ltd. (SAMC), Shanghai Aircraft Customer Service Co., Ltd., Beijing Civil Aircraft Technology Research Center (BCATRC), and Shanghai Aviation Industrial (Group) Co., Ltd. (SAIGC).

programme and in June 2011 COMAC and budget airline Ryanair signed a Memorandum of Understanding to participate in discussions on the development of the COMAC C919 http://www.ryanair.com/en/news/ryanair-and-comac-commercial-aircraft-corp-of-china-sign-c-919-mou-in-paris. The COMAC C919 is a short-medium range commercial trunk liner with a capacity of 156-168 seats. It will be elaborated on later in the 'knowledge and technology' section.

4.3.2 Knowledge & technology

4.3.2.1 Knowledge inflows from the global supply chain

Despite almost a six-fold increase on R&D expenditure on the aerospace sector between 1995-2006 (Hollander et al., 2008, p24. Box 4) and reorienting the industry towards civilian aviation projects in this period, still relatively little progress in terms of developing capabilities and processes, has occurred through indigenous efforts manifested by China's NSI. However, China continues to embed itself more deeply in the global supply chain in this sector, enhancing its breadth and depth of capabilities in aviation production techniques and products. Table 4 illustrates the growth in the range of work the Chinese are involved with[7]. China is learning and developing capabilities to a level that are valued by international players. To quote Mr Brun VP of Boeing's Commercial China operations:

> 'The suppliers here are actually very good…For a particular part, these suppliers bring some of the best capability in terms of value, and ability to meet our production rates, and quality.' (Teslik 2007a)

Additionally, a significant event in the evolution of the Chinese aviation industry's role in the global supply chain was the building of an A320/319 assembly plant in Tianjin (a replica of its Hamburg plant) by Airbus in 2008. All aircraft assembled in the Tianjin facility are understood to be equal quality to those assembled in Europe (Szepan, 2012). This suggests that this facility provides China an opportunity to leap closer to the knowledge frontier of aviation assembly. Whilst no specific technologies may be exchanged here, the opportunities for learning about processes, the organisational of work, the management of a globally distributed supply chain, the

[7] If read from the perspective of a western company, one can also gain an impression of the progression of the relationship with Chinese firms with individual western companies.

architecture into which the various components fit and their interfaces is undoubtedly invaluable to the Chinese as they themselves seek to become a systems integrator for the 21st century.

However, China is no longer satisfied with being a supplier to established systems integrators like Boeing and Airbus. The ARJ21 and C919 signal their ambitions through COMAC to become a systems integrator and a global challenger in their own right.

4.3.2.2 Continued but slow progress on the ARJ21

When officially inaugurated in 2001, the first flight test was targeted for mid-2006, CAAC certification in October 2007 and service entry by end 2007 (JAWA 2005-6) but this was always ambitious. Things lagged from the outset; the mid-fuselage by XAC was not delivered until September 2006 and the CAC-built nose section in December 2006. The first test flight occurred in November 2008, CAAC tests continue now. Delivery of the first plane to Chengdu Airlines has been delayed until late 2013. Many sceptics attribute these delays to a lack of Chinese competence, however neither of the new models by Boeing (787 Dreamliner) or Airbus (A380) have been delivered to schedule, or without the need for subsequent safety checks and technical revisions[8]. Some speculate that problems with the ARJ will mean that it too will be a commercial failure. However the ARJ may be seen as just another learning experience which will help the smoother development of the C919 narrow bodied jet.

4.3.2.3 The birth of a new programme – the COMAC C919

COMAC began the C919 Jet programme in 2011. It is China's first direct challenge to Boeing's 737 and Airbus's A320. Again an ambitious schedule for delivery was outlined: first test flight in 2014, in service by 2016. It intends to offer a 10% reduction in operating cost relative to its rivals, which with the rising price of fuel, would make it an attractive option. Savings will come from reduction the aircraft's

[8] Boeing's 787 first scheduled commercial flight was delayed by three years due to production problems and the global fleet of 50 were grounded worldwide in the middle of January 2013 due to battery faults causing fires (http://www.economist.com/blogs/gulliver/2013/02/boeings-787-dreamliner accessed 26/02/13). Airbus's A380 superjumbo's first commercial flight was two years behind schedule and since then, faults such as wing cracks and weakened rivet joints in the fuselage have come to light (http://www.telegraph.co.uk/finance/newsbysector/industry/engineering/9088801/Airbus-A380-superjumbo-hit-by-another-fault.html accessed 26/02/13).

weight through the use of composite structures and aluminium-lithium alloys (Wang, 2012 http://www.businessweek.com/news/2012-02-22/china-s-comac-to-sign-suppliers-for-c919-by-june-for-2014-flight.html).

In terms of knowledge and technology, most of the key components and subsystems are beyond China's capabilities and will be bought from foreign suppliers. 33 systems suppliers are anticipated and those which have been appointed to date are all are top tier OEMs that provide also systems for Boeing and Airbus (see Figure 4).

Whilst the systems are apparently subject to open competitive tendering, the reality is that the 'market for technology mindset' still holds and those foreign suppliers who offer the most in terms of collaborative work will win contracts. On the other hand, it is understood that 'suppliers on ARJ21 will have an advantage other terms being equal with other suppliers' (http://www.fac.org.uk/LinkClick.aspx?fileticket=ddCbb1fzvsI%3D&tabid=643 accessed 26/02/13). The body parts will be sourced from Chinese companies including: Shenyang, Chengdu, Xian, and Hongdu Aircraft Companies, all of whom were contracted to produce the same parts on the C919 as they were on the ARJ21 (Szepan, 2012). Thus, there is a certain path dependency in the knowledge development building from the ARJ21 which in turn builds on the MD80 and MD90 that were made in the Shanghai facilities in the 1980's and 90s. For those parts that are sourced from foreigners, the 'clean slate' of the C919 provides an opportunity to bring together all the latest sub-systems into one aircraft and leap to the front of the line in terms of the technological sophistication of their aircrafts' systems and subsystems. This is because the 737 and A320 are 20-30years old and whilst they have periodically undergone subsystems upgrades, they do not bring all the latest subsystems together as the C919 will do.

4.3.3 Institutions

The main institutional development is the partnership between the CAAC and the FAA. China knows it has a poor/no reputation for building commercial aircraft and whilst it may be able to 'persuade' domestic airlines to some degree that 50% of their fleet should be Chinese aircraft[9], in international markets it needs FAA certification. The CAAC-FAA relationship consists of an on-going series of joint safety efforts, data sharing and training programs with Chinese personnel visiting their US counterparts etc. The FAA was generally distant with respect to regulatory approval though because of potential conflicts of interest (Chinese aircraft have hundreds of US subsystems and components within them) but this changed with President Obama's announcement of closer collaboration in 2009. (http://online.wsj.com/article/SB10001424052748704204304574544043310821078.html accessed 14/07/2010).

Interestingly anecdotal evidence suggests the CAAC is determined to set its own standards to exceed those set by the FAA on aircraft safety. It also suggests that the CAAC have revised of their organisational culture to some degree. Historically COMAC blamed delays in part upon the difficulties of getting CAAC officials to coordinate their schedules with those of test flights, all of which require a CAAC official to be in attendance. The CAAC has improved its performance not only in certification programs, but also in its promptness in executing tasks such as inspecting materials and equipment. http://www.aviationweek.com/Article.aspx?id=/article-xml/awx_10_26_2012_p0-511368.xml&p=1 accessed 26/02/13.

Many problems still reside with inherited Chinese attitudes and mindsets. Again anecdotally, "As a Chinese state organization, COMAC is not in the habit of announcing program delays, as a Western manufacturer would do. It also has good reason not to be quick in letting even its suppliers know that there has been another schedule slip…If suppliers think that they have more time, they won't try so hard," says an industry official. Yet suppliers include AVIC itself, GE, Honeywell and a host of world class reputable companies (http://www.aviationweek.com/Article.aspx?id=/article-xml/awx_10_26_2012_p0-511368.xml&p=1 accessed 26/02/13). The presence of institutionalised cultural

[9] Whilst the ARJ21 boasts 252 on book orders (including options) and the C919, 50 orders these are almost exclusively from Chinese airlines and commentators note industry norms of deposits have not been paid. General Electric Capital's Aviation Service is the only non-chinese customer (with orders for 5 ARJ21's with options for 20 more, and 10 C919's) but they supply engines and avionics to both aircraft so a political relationship motive underlies these.

norms and behaviours continues to affect communications and hence efficiency of Chinese production.

4.3.4 DUI, learning strategies and capability building

For the post 2006 period, the DUI linkages in some ways continue on as previously – relatively little DUI between the Chinese companies themselves or with the research base or government, but much more between Chinese and foreign companies. However there are some changes. There appears to be more interaction and shared learning experiences between COMAC, AVIC Aircraft and the CAAC. There are deeper linkages between the CAAC and FAA on the standards, safety and certification areas. A significant twist is the role reversal that has taken place from China as a supplier to the incumbent system integrators to China becoming a systems integrator itself. Significantly, these tier 1 suppliers are having to transfer more knowledge, provide more training in order to secure their contracts in the ARJ21 and C919 projects. This will continue to contribute to the stock of knowledge China is building in its efforts to become a real challenger in the future.

The learning strategies do appear to be significantly more pro-active in the 11th 5 year programme than before. Dis-satisfaction with the returns from a passive learning strategy through outsourced activity to the generation of merely incremental innovation capabilities has led to the requirement for OEMS to provide more knowledge transfers in order to partake in the indigenous aircraft developments. This is an attempt to heighten active learning strategies and the speed and depth of knowledge transfer, with the aim of both more significant incremental innovation or even innovation capabilities (strictu sensu) in future.

5. Discussion

Through the synthesis of the NSI, SSI and NLS frameworks a novel approach has been developed and applied to the analysis of the Chinese civil aviation sector. This case study reveals the weak support the Chinese NSI provided to the civil aviation industry despite significant restructuring of the agents, their responsibilities, and incentives for innovative activity. However comparatively stronger support from foreign companies and agencies has helped develop the capabilities of Chinese firms to a level which might be described by Viotti (2002) as ‘incremental innovation capabilities’. The capabilities gained have been technological, but also broader in terms of organisational processes, managerial training, technical training for engineers, maintenance crew, pilots and support staff as well as CAAC officials. Much of this may have been given by foreign companies in part to be seen to be transferring knowledge to China to fulfil their obligations in return for access to the Chinese market, without giving away ‘the crown jewels’. However they have all helped China to develop capabilities in many areas which contribute to the mosaic of a successful aviation industry. China is attempting to build its own airplane because it has the demand from its increasingly wealthy population and that warrants investment in this area. However being able to build the aircraft technically is not enough. Safety certification to a globally recognised standard helps build reputation effects and brand. Similarly, airport infrastructure, air management systems, training of pilots, maintenance crew, etc., are all necessary for this demand to be met.

With regards to the technological knowledge that has been transferred, it has been carefully selected by the systems integrators and the tier 1 OEMs. For example, crucial knowledge about jet engines has not been transferred and Chinese attempts to reverse-engineer, imitate or develop their own have been frustrating and unsuccessful (Collins & Erickson, 2011). Without engines the Chinese will never be able to manufacture an entire aircraft using only Chinese suppliers yet this is ultimately where its ambition lies.

However China now needs to balance its continued engagement in the global supply chain with the strengthening of the DUI elements between the sectoral nodes in its *national* multi-layered system. In terms of policy recommendations, government level support and further incentives will need to be put in place to encourage Chinese firms to collaborate and share knowledge more through direct interaction rather than relying on government ‘plans’. At the firm level, policies to develop clear and open communication channels between firms and other agents in the economy are required. The firms need to build more and stronger bridges to the universities and science academies in the related technological fields appropriate to aviation. ‘How’ they can do this should be leveraged from their experiences of working with foreign companies and agents and through the professionalization of their attitudes to work, their methods of knowledge transfer and sharing. Without the creation of better DUI linkages in the NSI which supports this sector and the alteration of underlying institutional practices and attitudes, in the long run, at best China may see a few of its companies becoming tier 1 suppliers to the incumbent systems integrators of Boeing and Airbus as China's ability to innovate (strictu sensu) will become limited to strategic choices of individual firms in the absence of appropriate national institutional support.

6. Conclusion

China has clearly come a considerable way since its earlier experiences in the aviation sector. Whether it is yet at a stage where it is a real threat to incumbent systems integrators in either the regional or wide-bodied jet segments is unclear, probably not. Nevertheless the Chinese are pragmatic in their attitude to failures in this industry and each failed project is perceived to be another step up the ladder to their ultimate goal. When China manages to strengthen its DUI linkages through institutional reform and a gradual adjustment in mindsets (which may require another generation yet[10]) they will achieve their goals, it may just be a matter of time.

In synthesising three systems of technical change for its analytical foundation, this paper has illustrated the substitutability between national and international institutions and practices in the development of a particular industry when the national context is weak, but also how this sectoral development may be sub-optimal without strengthened national frameworks in the longer-term. Whilst the current case study does not yet illustrate it, it is likely that global sectoral systems of innovation will also benefit from including new national members in the long-run, however these ideas need to be tested in additional contexts. Nevertheless, further work on the relationships between NSI, SSI and NLS should be conducted as understanding their

[10] The current generation of Chinese graduates have experienced more Westernised educations, either because many have studied overseas, or because of the presence of Western Institutions like CEIBS or Ningbo, or because of the westernisation of the Chinese curriculum generally.

interdependency could lead to better policy formulations for national governments in late industrialising nations.

REFERENCES

Boeing (2013) Long-term market (CMO) Asia Pacific http://www.boeing.com/commercial/cmo/asia-pacific.html. Accessed 26/02/12.

Calver, P. (2009) The Chinese Aerospace Market and C919 Programme, UK Trade and Investment Presentation. http://www.fac.org.uk/LinkClick.aspx?fileticket=ddCbb1fzvsI%3D&tabid=643 accessed 01/04/10.

Collins, G. & Erickson, A. (2011) ‘A Chinese “Heart” for Large Civilian and Military Aircraft: Strategic and commercial implications of China’s campaign to develop high-bypass turbofan jet engines’, China SignPost, Issue 47, 21 pages.

Davies, A. & Hobday, M. (2005) The Business of projects: managing innovation in complex products and systems Cambridge University Press, Cambridge, UK

Dougan, M. (2002). A Political Economy Analysis of China's Civil Aviation Industry. New York and London, Routledge.

Duanmu, J.-L. and F. Fai (2007). "A Processual Analysis of Knowledge Transfer: From Foreign MNEs to Chinese Suppliers." International Business Review. 16: 449-473.

Fai, F. (2005). "Using intellectual property data to analyse China's growing technological capabilities." World Patent Information 27: 49-61.

Freeman, C. (1987) Freeman, C. 1987. Technology Policy and Economic Performance: Lessons from Japan, London, Frances Pinter

Fromhold-Eisebith, M. (2007), ‘Bridging Scales in Innovation Policies: How to Link Regional, National and International Innovation Systems’, European Planning Studies, 15:2, pp217-233.

Graham, A., Papatheodorou, A & Forsyth P. (2012), Aviation and Tourism: Implications for Leisure Travel. Ashgate Publishing, Ltd.

Goldstein, Andrea (2007), ‘The Political Economy of Industrial Policy in China: The Case of Aircraft Manufacturing’, Journal of Chinese Economic and Business Studies, 4(3), pp. 259-273.

Gu, S. and B.-A. Lundvall (2006). "China's Innovation System. Harmonious Growth and Endogenous Innovation." Innovation Management. Policy and Practice 8(1/2): 1-26.

Guan, J. C., R. C. M. Yam, et al. (2009). "Innovation Strategy and performance during economic transition: Evidences in Beijing, China." Research Policy 38: 802-812.

Hobday, M., Rush, H. & Tidd, J. (2000) Innovation in Complex Products and Systems, Research Policy, 29 (7-8). pp. 793-804.

Hollanders, H., Van Cruysen, A. & Vertesy, D. (2008), Sectoral Innovations in Europe: The Case of the Aerospace Sector. Final Report. Report for the Sectoral Innovation Watch project, Brussels: European Commission, DG Enterprise. Maastricht: 1-80.

Hu, M.-C. and J. A. Mathews (2008). "China's National Innovative Capacity." Research Policy 37: 1465-1479.

JAWA (various years), Jane's All the World's Aircraft: Development & Production. An IHS publication.

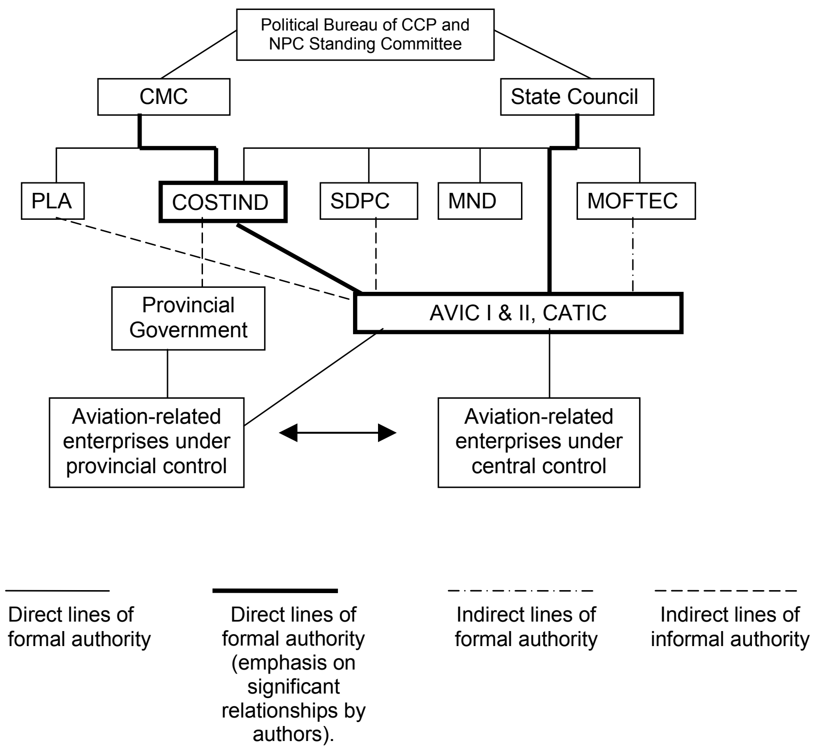
Jenkins, M. (2003) “30 years and counting. Boeing’s long relationship with China helped launch a major aerospace market”, Boeing Frontiers, Online December 2002/January 2003, Volume 01, Issue 08. http://www.boeing.com/news/frontiers/archive/2002/december/mainfeature.html accessed 22/02/13.

Keck, E. (2001) ‘Commercial aviation takes off’, The China Business Review,Vol.28, no. 2, pp14-16.
Leo, H., Reinstaller, A. & Unterlass, F. (2007), Analysing and Modelling Sectoral Innovation Systems: Introduction, Overview and Outlook, Final draft, Europe Innova, Work package 4.
Liang X., Lin L. & Wu G. (2009) Evolution of the Chinese Automobile
Industry from a Sectoral System of Innovation Perspective, Industry and Innovation, 16:4-5, 463-478.
Liu, X. and N. Lundin (2007). Towards a Market-based Open Innovation System of China. Globelics Academy. IST, Technical University of Lisbon
Liu, X., P. Lv, et al. (2009). China's Innovation System in Transition - BRICS National Innovation Systems. Beijing, China, Graduate University of Chinese Academy of Sciences (GUCAS): 104.
Liu, X. and S. White (2001). "Comparing Innovation Systems: a Framework and aplication to China's Transitional Context." Research Policy 30: 1091-1114.
Lu, Q. (1997). "Learning and innovation in a transitional economy: the rise of science and technology enterprises in Chinese information industry." INSEAD Euro-Asia Research Centre Working Paper(50).
Lundvall, B.-A. (1988). Innovation as an interactive process: from user-producer interaction to the national system of innovation. Technical Change and Economic Theory. G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg and L. Soete. London, Pinter Publishers Ltd.
Lundvall, B.-A. (2007). Innovation System Reserach and Policy. Where it Came From and Where it Might go. CAS Seminar Oslo: 1-50 pages.
Malerba, F. (2002a). "Sectoral Systems of Innovation and Production." Research Policy 31: 247-264.
Malerba, F. (2002b), ‘New Challenges for sectoral systems of innovation in Europe, DRUID Summer Conference 2002 on Industrial Dynamics of the New and Old Economy - who is embracing whom?, Copenhagen, Denmark, June 6-8.
Malerba, F. (2004). Sectoral Systems of Innovation. Concepts, Issues and Analyses of Six Major Sectors in Europe. Cambridge, Cambridge University Press.
Malerba, F. (2005). "Sectoral Systems of Innovation: A Framework for Linking Innovation to the Knowledge Base, Structure and Dynamics of Sectors." Economics of Innovation and New Technology 14(1-2): 63-82.
Malerba, F. and S. Mani, Eds. (2009). Sectoral Systems Of Innovation And Production In Developing Countries. Cheltenham, UK, Edward Elgar.
Motohashi, K. (2008) ‘Assessment of technological capability in science industry linkage in China by patent database’, World Patent Information, Vol. 3. Issue 3, pp.225–232.
Motohashi, K. and Yun, X. (2007). "China's Innovation System Reform and Growing Industry and Science Linkages." Research Policy 36: 1251-1260.
Nelson, R. R. (1993). National Innovation Systems: a Comparative Advantage. Oxford, Oxford University Press.
Nolan, P. (2001). China and the Global Economy. National Champions, Industrial Policy and the Big Business Revolution. Basingstoke and New York, Palgrave.
Nolan, P & Zhang, J. (2002), ‘The Challenge of Globalization for Large
Chinese Firms’, World Development, Volume 30, Issue 12, December 2002, pp.2089-2107

Nolan, P. and J. Zhang (2003). "Globalization Challenge for Large Firms from developing Countries: China's Oil and Aerospace Industries." European Management Journal 21(3): 285-299.
Perrett, B. (2009), ‘Chinese Advances’, *Aviation Week Space and Technology* 26/01/2009, Vol 170/4 p313-4.
Prencipe, A (2000) Breadth and Depth of Technological Capabilities in Complex Product Systems: The Case of the Aircraft Engine Control System, Research Policy, 29, pp. 895-911
Sholem, D. R. (1993). "Flying High." China Business Review (May-June): 20-22.
Sweeney, P. (2008). "Flying Without Suceeding? Assessing the Future of the Civil Aviation Manufacturing Sector in the People's Republic of China." Journal of International Policy Solutions Volume 8(Winter): 3-12.
Szepan, M. (2012) Changing the Rules of the Game: The Commercial Aircraft
Industry in China, Harvard Asia Quarterly, Spring/Summer, Vol.14, no.s 1&2 pp. 112-122.
Tang, M. & Hussler, C. (2011), ‘Betting on indigenous innovation or relying on FDI: The Chinese strategy for catching-up’, Technology in Society 33, pp. 23–35.
Teslik, L. H. (2007a) ‘In Depth. Bruns: China Aerospace Industry Presents Challenges, Opportunities’, Council on Foreign Relations, October 8 2007. www.cfr.org/publication/14392/chinese_aircraft_take_flight.html?.. Accessed 10/10/12.
Teslik, L. H. (2007b), ‘Backgrounder. China’s Motor Vehicle and Aerospace Industries’, Council on Foreign Relations, October 8 2007. www.cfr.org/publication/14399/chinas_motor_vehicle_and-aerospace_industries.... Accessed 10/10/12.
Vertesy, D. & Szirmai, A. (2010), ‘Interrupted innovation: Innovation system dynamics in latecomer aerospace industries’, UNU-MERIT Working Paper 2010-059
Viotti, E. B. (2002). "National Learning Systems. A New Approach on Technological Change in Late Industrializing Economies and Evidences from the Cases of Brazil and South Korea." Technological Forecasting and Social Change 69: 653-680.
Williams, A. (2009) Contemporary Issues Shaping China’s Civil Aviation Policy, Ashgate Publishing Ltd.
Wilsdon, J. & Keeley J. (2007). China: The Next Science Superpower? The Atlas of Ideas: Mapping the New Geography of Science. C. Leadbeater and J. Wilsdon. London, DEMOS: 69 pages.
Zhang, X. (2002), “China, the Soviet Union, and the Korean War: From an Abortive Air War Plan to a Wartime Relationship”. Journal of Conflict Studies, North America, 22/1, Aug. Available at: http://journals.hil.unb.ca/index.php/JCS/article/view/368/582. Date accessed: 22 Feb. 2013.

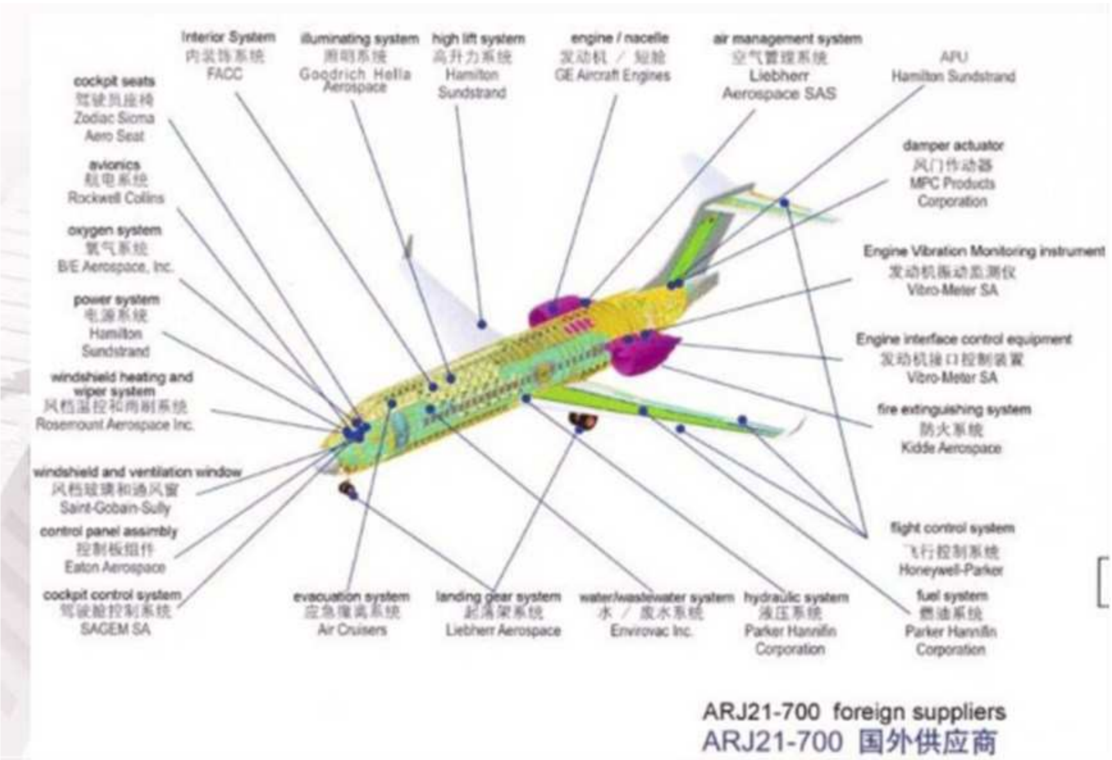
FIGURES

Figure 1: The Aviation Manufacturing Administrative System circa 1999.



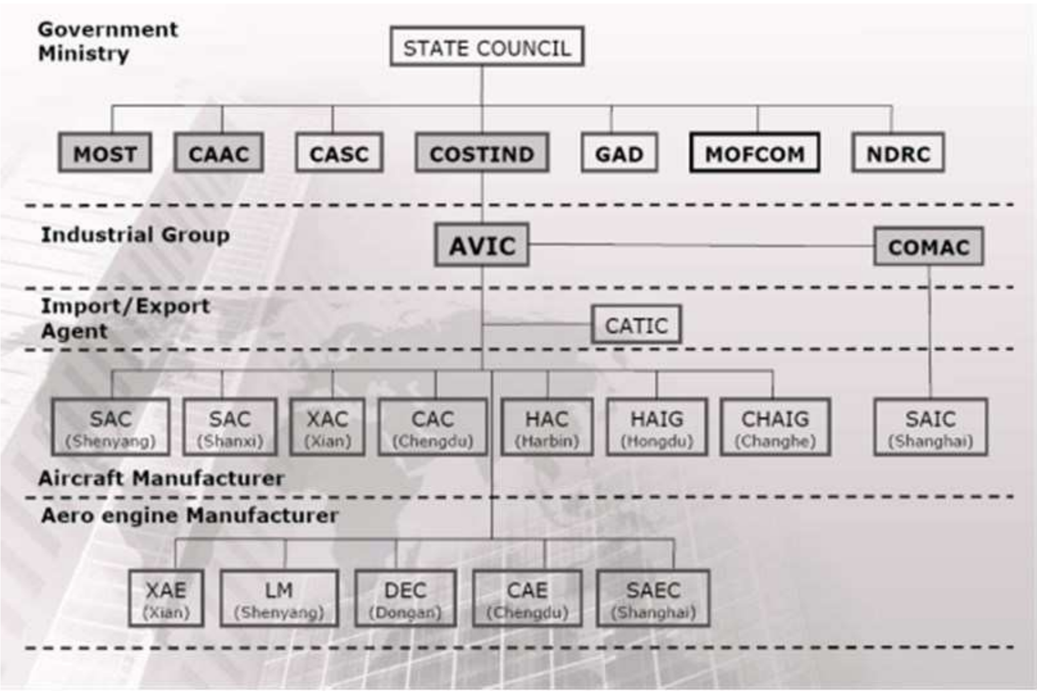
Adapted from Dougan (2002, p.95)

Figure 2: Foreign suppliers of systems and components in the ARJ21



Source: Calver, 2009

Figure 3: Administrative structure of the Chinese aviation sector circa 2008



Source: Calver, 2009

Figure 4: Diagram of China C919 aircraft parts suppliers

Source: [http://www.jeccomposites.com/news/composites-news/diagram-china-c919-aircraft-parts-suppliers accessed 26/02/13](http://www.jeccomposites.com/news/composites-news/diagram-china-c919-aircraft-parts-suppliers).

TABLES

Table 1: airlines under CAAC control in 1985

• Air China	• China Southwest
• China Eastern	• China Northwest
• China Southern	• China Northern

Source: Graham et al. (2012)

Table 2: Original 6 companies in the ARJ21 consortium

• Chengdu Aircraft Industry Group (CAC)	• Shenyang Aircraft Corporation (SAC)
• Shanghai Aircraft Research Institute (SARI)	• Xian Aircraft Design and Research Institute (XADRI)
• Shanghai Aircraft Industry Company (SAIC)	• Xian Aircraft Company (XAC)

Table 3 – Six businesses from the former AVIC

AVIC (Defense division)	A direct part of AVIC. **Owns** military production facilities at Chengdu, Shenyang, Xian, all of Hongdu Aviation Industrial Group and part of Guizhou Aviation Industry. **Makes** fighter jets, trainers and missiles. Corp.
AVIC Aircraft (formerly Transport Aircraft Co.)	**Owns** civilian components of the original AVIC's subsidiaries at Chengdu, Shenyang and Xian. **Makes** derivatives of the Russian aircraft (An-26 and Y-8 transport). Developing the MA700 turbo prop. **Subcontractor** to Boeing's 747 & 787, Airbus's A320 and structures for the COMAC ARJ21.
Avicopter	**Owns** all rotary wing plants notably at Haribin, Chenghe and Jingdezhen. **Makes** all Chinese helicopters (in association with Europcopter and Augusta Westland) and fixed wing transport. **Subcontractor** to Sikorsky.
General Aviation Co.	**Owns** Shijiazhuang Aircraft and some of Guizhou Aviation. **Makes** light and ultra-light aircraft and seeking to build a business jet.
Aviation Engine Corp	**Owns** plants and research centres at Liming, Xian, Chengdu and Zhuzhou and the gas turbine establishment at Jianyou. **Makes** turboshaft and turboprop engines and trying to develop a regional jet turbo fan.
Aviation Systems Co	**Owns** approximately 40 disparate factories and research institutes with a view to competing with Rockwell Collins, Thales, Honeywell and Goodrich. Major facilities at Shanghai, Xian and Nanjing.

Source: Compiled from Perrett (2009).

Table 4: Chinese production capabilities via sub-component manufacturing for Western OEMs as at 2007-8

2007-8			
Chinese manufacturer	Subcontractor to	Aircraft Model	Component produced
CAC/CCA	Airbus	A320	Passenger doors
	Boeing	737	Wing components
		747	Wing components
		757	rear fuselages
			tail surfaces
	Dassault Falcon	2000EX	fuselage components
GAIC	Airbus		Maintenance jigs & tools
HAI	Boeing	airliners 787	metallic & composite parts
HAIG (formerly HAIG, Harbin)	Embraer	ERJ-145	fuselage frames
SAIC	ATR	ATR72	Components
	Boeing	737	Components
SCA (Formerly SAC, Shenyang)	Airbus	A319	Wing Ribs
			Emergency Exits
		A320	Wing Ribs
			Emergency Exits
	ATR	ATR42	Wing tips
			Rear fuselage sections
			Wing boxes
	Boeing	All	Other machined parts
		737-700	rear fuselage
			tail components
		747	floors
			bulkheads
		757	Cargo doors
		787	Fin leading-edges
	Bombardier	Dash8Q-300	Doors
			front Fuselages
			rear fuselage
	Lockheed Martin	C-130	Tailcone
			Landing gear
			pylon components
XAI (formerly XAC)	BAE		Other machined parts
	EADS		Other machined parts
	Airbus	A320	Wing components
			Doors
	Boeing	737	Fins
			Tailplanes
		747	Fins
			Tailplanes
		747	Wing trailing-edge ribs
		747-700 Special freighter	Floor beams
	Bombardier	415 Amphibian	glass fibre header tanks
			Water float pylons
			Ailerons
			Doors

Source: JAWA (2003-2009)