When shakeout doesn’t occur
The evolution of the turboprop engine industry

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Abstract

A careful case study of the history of the turboprop engine industry (1948–1997) is offered as an example of non-shakeout pattern. The persistence of high concentration is not associated with the exit of smaller manufacturers, but instead a stable coexistence of generalist and specialist strategies emerges, in sharp contrast to the pattern observed in the, otherwise similar, jet engine industry. This paper identifies the relevant variables of a more general theory of industry life cycle by taking into account the lack of creation of significant increasing returns in R&D, manufacturing or marketing, all of which are commonly found in industries that produce systemic products. ©2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The industry life cycle has become one of the most important models of long run industry evolution, since it is consistent with most of the empirical evidence on industry growth and articulation.

The importance of structural models of this kind cannot be undervalued. If their general validity can be demonstrated, they offer important elements for understanding the nature of competition at any given time in an industry and may provide useful prescriptions for strategic management decisions. Therefore, the problem of general validity of the model becomes crucial. This explains the attention which is given in the recent literature to observed anomalies, or to industries that apparently do not follow the predicted pattern.

The paper has three main goals.

First, it develops a detailed case history of the entire life of the turboprop engine industry (1948–1997), by taking advantage of a proprietary database, that we built upon several sources of data. In this industry the persistence of high concentration is not associated with the exit of smaller manufacturers, but instead a stable coexistence of generalist and specialist strategies emerges, in sharp contrast to the pattern observed in the, otherwise similar, jet engine industry.

Second, through the analysis of the case history, it contributes to a theory of non-shakeout pattern by operationalising some of the relevant variables. This
is an important complement to the ILC theory, insofar it offers a framework for explaining observed anomalies. In particular, we focus on structural conditions that may or may not lead to the emergence of increasing returns in R&D, manufacturing or marketing activities. Market demand is analysed with respect to the level of segmentation and the sourcing strategies of customers. Cost structures are investigated with respect to the existence of economies of scope across product lines, mainly in R&D and manufacturing. In the latter case, since structural conditions are difficult to detect directly, the paper proposes a sensible strategy for measuring them indirectly.

Finally, the paper contributes to empirical research on industries in which products have a systemic nature. In these industries there are many reasons to expect significant deviations from the ILC pattern. This paper provides a comprehensive framework for the analysis of the long-term evolution of these industries, with many important managerial implications.

The paper is organised as follows. Section 2 offers a review of the ILC literature and proposes a categorisation of non-shakeout patterns. Section 3 describes the data. Section 4 analyses the history and the structural dynamics of the turboprop engine industry. Section 5 provides an explanation of the observed non-shakeout pattern, while Section 6 offers some conclusions.

2. Non-shakeout patterns in the evolution of industries

The problem of general validity of the industry life cycle (ILC) model has fuelled much research.\(^1\)

Nelson (1999) reviews several studies on long-term industry evolution and calls attention to cases that do not fit into the standard industry life cycle pattern. In this perspective, he argues that the ILC model does not take adequately into account the role of institutions in shaping industry structure and uses a simplistic notion of technical change, as it is based on the existence of a single technological cycle. On the contrary, a number of industries have been characterised by technological discontinuities during their life cycle (Anderson and Tushman, 1990; Christensen and Orsenigo, 1997) or by gradualism and punctuation in the process of technological development (Levinthal, 1998).

While the majority of studies have analysed shakeout patterns of industry evolution, more recent research is directed to identify cases of falsification of crucial predictions of the model (Nelson, 1994; Malerba and Orsenigo, 1996). In this context, much attention has been devoted to cases of ‘non-shakeout’, that is, industries whose long-term evolution has not been marked by a stage of massive exit of firms and net decrease in the number of competitors.

Klepper (1997) offers a thorough review of the existing literature on life cycle patterns and identifies three different cases of ‘non-shakeout’. It is interesting to study this paper closely since it constitutes a landmark of the literature. Klepper suggests that non-shakeout occurs in the following.

1. Industries in which there is a separation between firms that design and manufacture products and specialist firms that develop process technologies and sell them on a competitive basis.
2. Industries in which firms that develop product innovations do not appropriate their benefits through the integration of manufacturing activities but license new products to other manufacturers.
3. Industries in which the final demand is highly heterogeneous and fragmented, so that there is no emergence of leaders covering all segments and no shakeout of small competitors.

For several reasons that will become clearer below, we show that the first and second cases are two
special cases of a more general class (let us call it Class I). The third case, in turn, is a special case of another more general class (Class II). The two classes, taken together, cover all known violations of the classical ILC pattern. In this paper, we provide detailed evidence of a non-shakeout pattern, which is a new case in Class II, not covered so far in the literature.

With respect to case (1), a very important example is the petrochemical industry analysed by Arora (1995).²

Before the Second World War, large chemical manufacturers used to develop their productive process in-house, by using proprietary technologies and benefiting from extensive processes of learning about the efficiency of incremental modifications to existing plants. Process technology was therefore highly appropriable and any investment in process R&D had a very high rate of return, since it was rapidly reflected in diminishing production costs and higher profits. In this case one would expect large incumbents to gain cumulative advantages over late entrants and smaller firms, leading to a restructuring and consolidation of the industry. Yet this did not happen.

The reason is that by the end of the war in the United States a sector of independent process specialists was born. Internal developments of chemical process technology and the strong growth of academic chemical engineering disciplines had contributed to the complete codification of the technology underlying many important chemical plants. One of the main carriers of this process was the emergence of professional societies of chemical engineers, mixing together corporate specialists, academicians and consultants. Newly formed independent process specialists began to sell their technology worldwide, leading to a diffusion of chemical technologies and eroding the advantages of large incumbents. The emergence of process specialists requires at least two conditions that historically have been met simultaneously: a strong and pervasive process of codification of technology, which eroded appropriability, and a robust growth in demand. Pattern (1) is therefore a case of vertical separation between process R&D and manufacturing.

Pattern (2), instead, is a case of vertical separation between product R&D and manufacturing. A relevant example is the medical diagnostic imaging product market. The characteristic of this industry is that product innovators license their design to other manufacturers. In this case the presence of independent product developers makes it impossible for incumbents to appropriate exclusively product technologies and to build a cumulative advantage based on economies of scale in manufacturing. Basically, it becomes too risky to invest heavily in standardised process technologies, since incumbents do not fully control the interface with product technology.

The vertical separation between, respectively, product and process R&D and the manufacturing stage breaks the mechanism by which increasing investment in R&D builds and protects over time the conditions supporting incumbents’ dominance. Vertical separation can therefore be seen as an event which induces a new trajectory, by radically changing the appropriability conditions. This transition, which is not implicit in the technological regime, prevents the shakeout pattern from taking place.

In pattern (1), in fact, vertical separation prevented the emergence of the effects of a Schumpeter Mark II regime. In fact, the appropriation of benefits from process R&D would have created cumulative effects of sustained advantage for incumbents. This means that, lacking the emergence of independent process specialists, the industry would have undergone a classical ILC pattern. To illustrate this point, let us build up a counterfactual story.

After the war in the petrochemical industry the symptoms of the emergence of economies of scale and scope in the development of process technology are clearly visible. Supposing that this were not the case, then there would be no reason for independent process technology suppliers to enter the market. In fact, if the design of manufacturing process is strictly dependent on the design of products, then product innovators have an inherent informational advantage over other firms and no independent supplier is likely to emerge. Under these conditions, if appropriability can be preserved (for example through the

² Other examples are disposable diapers and zippers.
in-house design and manufacturing of plants) and the economies of process R&D are kept organisationally integrated with the economies of manufacturing, then the industry clearly follows the typical shakeout pattern. While appropriability of benefits from process technology by incumbents and large economies of scale in manufacturing invariably lead to a restructuring of the industry, the emergence of process specialists erodes the appropriability of benefits from process technology, and more specifically lowers the barriers to the entry of new competitors on a worldwide basis. This event marked a discontinuity into an evolution that would have otherwise followed a shakeout pattern. The eventual trajectory was not implicit into the underlying technological regime.

In pattern (2), in turn, vertical separation between product R&D and manufacturing prevented the transition from a Schumpeter Mark I regime of product innovation with large uncertainty over the dominant design to a Schumpeter Mark II regime in which the winning innovator can appropriate the benefits by investing in large manufacturing capacity. Again, the counterfactuals help to understand the underlying dynamics: if product innovations had not been licensed to many independent suppliers, but appropriated by the original innovator and, if product technology had been standardised, then these industries would probably have followed a classical life cycle evolution.

The crucial point in both cases is that vertical separation radically alters the appropriability conditions of the underlying technological regime and projects the industry along a different trajectory. These industries do not incur shakeout because they have been ‘displaced’ from their natural trajectory by the change in appropriability conditions.

Let us discuss pattern (3). As examples of this pattern, Klepper (1997) quotes the evolution of the laser industry, and the persistent fragmentation of the corporate jet industry analysed by Phillips et al. (1994). The explanation for the anomalous pattern in these industries lies in the lack of economies of scale in marketing activities. Customers are specialised by segment and do not buy products across segments. Therefore cross-selling is not possible and other marketing synergies across segments are lost. Customers’ needs are highly idiosyncratic and require careful adaptation of products. Due to these factors, customers do not attach value to global brands covering all market segments, but rather favour specialised suppliers.

For example customers may perceive disutility in observing the same manufacturer producing products in different segments. They may prefer a specialised supplier because they perceive it to be allocating more effort to their care. In a word, manufacturers operate in different markets, which can be aggregated only in a statistical sense but remain separate from the marketing point of view.

This explanation of the non-shakeout pattern is interesting, but incomplete. It is not possible to predict a non-shakeout pattern from information on demand, without adequate information on cost structures. In fact, the mere segmentation and fragmentation of demand is not a sufficient condition for the non-shakeout pattern to emerge. The crucial question is: why is it not possible for the same manufacturer to cover all market segments and dominate the market by using different brands?

If the cost structure is characterised by strong economies of scale and scope, then all disadvantages coming from heterogeneity of customers and independence of submarkets can be overcome by a multi-brand strategy, possibly backed by a multidivisionalised structure.

The only reason why such a strategy would not be viable is, in fact, the lack of increasing returns in the cost structure. For example, there may be intense difficulties in managing heterogeneous customer requirements within the same organisational structure. The preferences of customers may in fact be highly idiosyncratic, so that manufacturers need extensive learning to serve them carefully. Marketing knowledge, in this case, is likely to be very subtle and tacit, so it cannot be transferred easily within the company. Launching new products requires a lot of deep and sympathetic understanding of the market, based on cycles of learning and unlearning. The transfer of information from marketing to the technical and design departments may be extremely difficult. Therefore the divisionalised structure may not be effective in giving the corporate level sufficient information on divisional performance. In addition, a multidivisional corporation may experience intense internal competition leading to severe coordination problems. Under these conditions, there may be se-
vere diseconomies of scope, so that specialised suppliers are more efficient than large suppliers operating over many segments.

But, on the contrary, if there are no diseconomies in the cost structure, then market fragmentation per se is not sufficient to prevent the shakeout. Take for example the camera industry. There are many specialised user segments, with very weak communication of marketing information across them (Windrum and Birchenall, 1998). So professional users are not likely to influence amateurs via word-of-mouth information, and brand reputation is specific to each segment. Nevertheless, there are strong economies of scope in product R&D, so that solutions developed for one segment may prove valid, with modifications, for other segments. As a result, the industry is composed of large all-range competitors.

In sum, the industry life cycle dynamics are based on two conditions: appropriability and increasing returns.

The appropriability condition requires that the benefits arising from investment in R&D be at least partially appropriable by the investing agent. This condition holds differently for product and process R&D. In the former case, due to imperfections in the protection of property rights, appropriability requires the agent to invest also in complementary assets and integrate downstream until the commercialisation of new products. In the latter case, industrial secrecy practices and restricted access to firms' premises normally guarantee that the investment in process R&D is almost entirely appropriated by the investing agent. Both conditions are important for the ILC model to hold. Appropriability of product R&D is necessary for giving innovators the incentive to develop marketable products; this fuels the initial stage of the life cycle of the industry. Appropriability of process R&D is also necessary, if incumbents are bound to increase the ratio between process and product R&D in the maturity stage. If the benefits from process R&D were not appropriable, there would be no advantage for incumbents to invest largely. After the reduction of uncertainty over design parameters, the resulting reduction in production costs would benefit competitors via spillover effects.

Shakeout is not only the effect of economies of scale in manufacturing. If the consolidation of the industry were only a matter of capacity, with no role for process R&D, then all competitors, including late entrants, would engage in a capacity race with the objective of dominating the industry. The critical point is that only the firms that invested in the dominant design trajectory, and then developed a consistent process technology, would have the ticket to take part in the capacity game. This means that process technology is not freely accessible to all competitors in the industry. While appropriability of process technology is the rule rather than the exception, it may happen that, as in the chemical industry, external developments prevent the appropriation of fundamental process knowledge and made it freely accessible to new entrants.

With respect to the increasing returns condition, the discussion of pattern (3) leads us to a solid conclusion. The emergence of a shakeout can be prevented if there are no increasing returns in R&D, manufacturing or marketing activities. The long-term outcome of the dynamics of the industry is the result of a balance of effects. Disadvantages in marketing due to demand heterogeneity can be overcome if there are sufficient economies in R&D or manufacturing, by using a multi-brand, multi-divisionalised strategy. Disadvantages in R&D or in manufacturing due to different technologies and technical requirements can be overcome if submarkets are highly interdependent, by subcontracting or purchasing part of the product range.

As a result, there are two general classes of violations of the ILC model: violations of appropriability and violations of increasing returns.

The former (Class I) comprises all cases in which either product or process technology becomes non-appropriable, so that the incentive to invest in R&D is eroded and no competitor is in a position to gain sustainable advantages over the others. The most important cases of violations of appropriability are dependent on a process of division of labour, which leads to the vertical separation between, respectively, product and process R&D and the manufacturing stage. Vertical separation creates a market in-between the originator and the users of an innovation, and therefore prevents the monopolistic appropriation by any of the users. However, other cases are still possible in this class of violations (e.g. changes in the intellectual property rights regime).
The latter (Class II) comprises all cases in which increasing returns are not found in various stages of firms’ activities (R&D, manufacturing or marketing). The lack of increasing returns threatens the basis of the cumulative advantage of incumbents. On one hand, barriers to entry due to cost differentials are hard to sustain over time. On the other hand, it also becomes impossible to undercut potential entrants through preemption in a capacity game or via reputation effects. In this class of violations there are possibly many cases, due to possible combinations of return conditions at various stages of firms’ activities. The case discussed in Phillips et al. (1994) is one of lack of increasing returns in the marketing stage, due to persistent heterogeneity of customers’ preferences. The case discussed in this paper is one of lack of increasing returns in R&D, manufacturing and marketing. Bonaccorsi and Giuri (1999) discuss the case of the jet engine industry, in which there are increasing returns of R&D and marketing, but the hierarchical structure of the network of vertical relations with the customers prevents major players to exit the industry. Other combinations are possible here, whose net outcome cannot be predicted in general terms, but rather requires careful empirical appreciation and analysis.

In this paper we argue that demand segmentation is not sufficient to produce a non-shakeout pattern and that a more comprehensive explanation must take into account and balance accurately cost structures in R&D, manufacturing and marketing activities.

Most of the industries in which products have systemic nature fall naturally into this category. It is often argued that systemic industries do not share many features of mass production industries (Miller et al., 1995; Bonaccorsi et al., 1996; Hobday, 1998). The main differences between the two types of industries are clearly reflected into increasing returns in R&D and marketing or manufacturing.

In fact, in R&D activities systemic industries may have variable conditions of increasing returns, but in general the ratio between up-front or application-specific expenditures and activities whose results can be spread over many products is quite high.

In manufacturing, systemic industries produce in small batches or even single units, so that large economies of scale and benefits from standardisation are virtually lost. Product and process technology cannot be easily separated. Manufacturing technologies are often of general purpose type.

With respect to marketing, features of demand such as customer heterogeneity, demand discontinuity and the importance of relational investments all point to lack of significant economies of scale and scope in dealing with customers.

On the contrary, systemic industries are unlikely to experiment the violations of ILC pattern originated by changes in the appropriability regime. In fact, the systemic nature of products strongly favours the appropriability of results of investments into product R&D, even without patent protection, since reverse engineering is extremely difficult and spillover of limited technical information is useless for competitors. On the other hand, investments in process technology are highly appropriable, since machine tooling, and in some case even plants, are often co-designed with products. As a result, it is unlikely that these industries witness processes of division of labour that are based on the separation between product and process R&D and manufacturing.

In sum, the framework we propose for explaining cases of non-shakeout greatly contributes to a theory of industry evolution which applies to both mass- and non-mass-production industries.

3. Data and methodology

As an example of non-shakeout pattern, we study the life cycle of the turboprop engine industry.

This section provides background information about the nature of the data and our treatment for the objectives of this paper.

We work on different sources of data to reconstruct the history of the industry, precisely Atlas Aviation database, Jane’s All the World’s Aircraft (1940–1998) publications, some literature on the history and technological development of the aviation industry and technical press (in particular, among others, Miller and Sawers (1968), Phillips (1971), Constant (1980), Bluestone et al. (1981), Bright (1978), Vincenti (1990), Norris and Wagner (1997), and Sutton (1998).
Flight International and Aviation Week and Space Technology).

Atlas Aviation Database contains all the transactions occurring from 1948 to 1997 between aircraft manufacturers and airline companies in the market for large commercial and regional aircraft. The data distinguish the engine technology adopted, jet and turboprop, and for each transaction it is possible to identify the engine model integrated into the aircraft ordered. The database provides data on more than 85,000 transactions, carried out by 27 aircraft companies and 11 engine manufacturers, and involving 102 aircraft models (more than 450 versions) and 260 engine types. For the purpose of this study, we use data relative to turboprop engine and aircraft transactions. For each transaction the database provides 3-monthly dates: contract, first flight (also indicated as production date), and delivery. We use the first flight as unit of analysis as it is subject to less fluctuations. To reduce discontinuity in the data, monthly dates are transformed in annual dates.

We integrated the Atlas database with data on the number of engines powering each aircraft and on the seat capacity, by using other sources: Jane's All the World Aircraft publications and technical press (in particular, engine and aircraft directories of Flight International and Aviation Week and Space Technology).

Data on seat capacity, and information about segmentation by seat provided by company reports (in particular Boeing, Airbus, Aerospatiale), allows to trace the history of the turboprop industry and of each seat-segment of the market. The structure of supply and demand is also studied at the level of market segment.

Entry is defined as the first date an engine manufacturer supplies an engine to an aircraft manufacturer (indicated by the date of production). A firm experiences exit when it does not supply engines for at least five consecutive years.

Data on which concentration measures are computed are based on total sales of commercial aircraft manufacturers, expressed in physical quantities (orders). To take into consideration sales of aero-engine firms, aircraft orders are multiplied by the number of engines installed in the model, as described in the technical literature. Market shares are therefore defined in terms of quantities rather than turnover, since there is no such detailed price information available at the level of individual aircraft and engine programs. We compute two concentration measures: the CR(K) and Herfindahl indexes (Grossack, 1965; Boyle and Sorensen, 1971; Curry and George, 1983; Baldwin, 1995).

Data on market relations are finally used to identify the sourcing strategies of turboprop aircraft manufacturers at the company and at the aircraft program level.

The empirical analysis is organised as follows. Section 4 presents the historical evolution of the turboprop engine industry, emphasising the emergence of the turboprop market as independent of the jet market, and focuses on the structural evolution of the industry in terms of entry, exit, number of firms, concentration and dynamics of market shares.

The observed non-shakeout pattern is explained in Section 5 by structural characteristics of the industry referring to the demand and the cost side.

4. The evolution of the commercial turboprop engine industry

4.1. History of the turboprop aircraft-engine industry

4.1.1. 1948–1977

From the beginning of the powered aircraft industry until the Second World War, the propeller-piston engine combination was the prominent aircraft propulsion system. Difficulties encountered in further developing piston engines induced the search for alternative forms of propulsion systems, ranging from different forms of piston engines, to gas-turbine driven turboprop and turbojet powered systems (Constant, 1980).

The search for alternative forms of propulsion systems was driven by the military need to operate at higher altitude and speed in order to avoid counter-air defence. The successes and failures experienced during the inter-war period while trying to meet these requirements by developing gas turbines did result in the affirmation of two propulsion systems: turboprop, using an internal combustion gas turbine to drive a conventional propeller, and turbojet, using an internal combustion gas turbine as gas generator and a reaction propulsion nozzle as thrust producer.
Each propulsion system was designed for specific ranges of operating conditions (aircraft speed, altitude, air density and temperature, passenger capacity).

Military needs for turboprop were less pressing, because of the higher performances promised by the turbojet technology, but the turboprop was of more immediate interest to the airlines than the jet (Miller and Sawers, 1968).

The 1950s represented a transition period for the airliners, as air carriers adopted the jet or turboprop engined designs for some operations, but continued to buy piston engines for others (Kingsley-Jones, 1999a).

The first turboprop airliner was the 60-seat Vickers Viscount powered by four Rolls Royce Dart engines. It first flew in 1948 and entered in service in 1953. In 1955 Fokker launched the first 40–50 seat F27 twin turboprop, powered by the Rolls Royce Dart. In 1957 Lockheed introduced the 90-seat L-188 Electra powered by the Allison 501 to compete with the Vickers Viscount.

The 1950s also witnessed the appearance of turbojet airliners, marked by the successful introduction of the B707 and DC8 in 1958. New jet powered aircraft provided higher speed, but costs were extremely high for short routes. This explained the survival of the piston-engine powered DC-3, the introduction of turboprop aircraft to replace the DC-3, and the subsequent development of the turbofan. The jet engine provided the ability to power larger and faster aircraft than could be built with piston engines, bringing larger savings on the longer routes. The turbojet engine was more efficient than a piston propeller engine at speeds over about 450 mph. (Miller and Sawers, 1968). At medium speed and altitudes the turboprop was generally more efficient than a pure turbojet. Its main disadvantage was that it carried with it all the weight and complexities of mechanical characteristics of any propeller system.

This period was characterised by high uncertainty about the cost performances of jet and prop technologies and by intense competition between the two systems. Jet engines worked efficiently only when a long cruising period was balanced against the costs associated with fuel consumption during taxiing, take-off and landing. On the opposite side, the problem of turboprop engines was the relative cruising speed: because propeller tips quickly came into the critical Mach region, their practical maximum flying speed was generally low.

In 1960 the turboprop Vickers Vanguard powered by a RR Dart was introduced in the segment of 91–120 seats. However, further design innovations in the turbojet, such as the turbofan, provided at that time much greater propulsive efficiency and supersonic performance. This conclusively established the advantage of the turbojet in this segment, forcing the turboprop Vanguard to exit the market after only 5 years.

Fig. 1 exhibits the share of turbojet and turboprop on the total market for aircraft with less than 120 seats, which is disaggregated into four segments defined by the seat capacity of the aircraft: less than 30, 31–50, 51–90 and 91–120 seats. As can be seen, the pattern of technological substitution is substantially different in the four segments.

As shown by Fig. 1d, the 91–120 seat segment is characterised by the former presence of turboprop airliners, and by the definitive substitution and dominance of the market by the jet aircraft.

By the 1960s the jet was the only option for long-haul routes, but airlines were unclear on their future strategy for short-haul operations. The success of the jet-powered Caravelle had encouraged the development of small jets in the segment of 51–90 seats, including the Fokker 27 and the DC9. However, other manufacturers continued to pursue turboprop designs, such as the Convair 600 and the Convair 580/640, powered by Rolls Royce and Allison engines, and Rolls Royce engines also powered Namco YS 11 and HP Herald.

The competition between jet and prop during the 1960s is visible in Fig. 1c. While at the beginning the turboprop was the only available solution, the entry of the jet reduced progressively the share of turboprop in the market.

The advantage of turboprop is clearly evident, instead, in the markets with smaller seat capacity. The segments of 31–50 and <30 seats were com-

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*The turbofan (ducted fan or by-pass engine) is a variant of the turbojet which combines qualities of pure turbojet and turboprop. It increases mass flows and reduces exhaust velocity, thereby raising propulsive efficiency at moderate speed.*
pletely dominated by turboprop airliners from their birth. The only exception in the period 1948–1977 was represented by the German 44-seat jet-powered VFW 614, which was launched in 1972 as an attempt to overcome the limits of the turboprop. It can be considered a failure as only 19 aircraft were sold from 1972 to 1978 (see Fig. 1b).

Finally, in the market for aircraft with less than 30 seats, shown in Fig. 1a, the only efficient solution is offered by the turboprop technology. The first aircraft emerging in this segment was the Nord 262 powered by the Turbomeca Bastanvic. In 1965 the engine producer Pratt & Whitney Canada entered the market to supply the de Havilland Dash 6. During the 1970s a number of other makers entered the market, including the Pilatus BN2A III Trislander powered by a Lycoming O540, the Casa 212 powered by the Garrett TPB 331 and the P&W powered Embraer 110, Let 41 and Short 330. This segment of the market met a large demand, ending up in representing the larger share of the market for turboprop aircraft.

The global composition of the turboprop aircraft industry by seat segments is presented in Fig. 2. While during the 1950s the market was composed mainly of 51–90 seater airliners, by the 1960s companies proposed aircraft of larger and smaller seat segments.
capacity. The 120-seat turboprop solution was short-lasting, the share of the 51–90 segment was progressively eroded by the jet airliners, while the segments for smaller seat capacity ended up covering the total market.

The evolution of the total market for turboprop engines is shown in Fig. 3. The birth of the industry is characterised by a continuous and rapid growth until the peak in 1959. After the introduction of the jet, the demand for turboprop engines sharply decreased. The second peak (1967–1968) was fuelled by the development of the market for aircraft with less than 50 seats, after which demand decreased again until 1975.

4.1.2. 1978–1998

A major event in the development of the market for turboprops was the Deregulation Act of 1978 in the United States. This brought the free access of airline companies to routes and the free determination of fares. Deregulation lead to an intensification of the competition among carriers, characterised by:

(i) a process of restructuring and increasing concentration of the airline industry;
(ii) a redistribution of the routes, as a consequence of the efforts of optimisation of the route structure undertaken by each air carrier, bringing about a large development of the regional market. The result has been the creation of a hub-and-spoke route structure for major/national carriers which face high density of air traffic. The low traffic routes have been redistributed across regional airlines (Aerospatiale, 1989; Airbus Industrie, 1991; FAA Forecasts and Technology Plans, 1994).

The effects of the creation of the hub-and-spoke route structure was twofold. On the one hand, as the airports saturated, hub feeds began to require aircraft of larger size, with ranges of 100–300 nautical miles. Consequently, the demand for turboprop aircraft of 31–50 seat capacity increased relative to aircraft with less than 30 seats. On the other hand, in hub-by-pass operations the typical range are 300–600 nautical miles, and these should ideally require a higher cruising speed than turboprops offer. As the time of flight for a turboprop aircraft should be below 2h, high speed is necessary for longer routes. This has lead to the renewed interest by several manufacturers in the new small regional jets (Marsch, 1989).

The redistribution of routes has been possible after a modification of a regulation which increased the limits of capacity for regional airlines from 19 to 60 seats (Aerospatiale, 1989). This has led to a considerable growth of the demand for aircraft with more than 19 seats. At the same time the role of regional airlines has enormously increased over time.

Therefore, the deregulation, more than any other factor, created the market for new turboprops. This has stimulated the development of new technologies for turboprop engines and aircraft, the introduction of many new programs and the entry of new actors. As shown in Fig. 3, after 1978 the market for turboprop engines was characterised by remarkable
rates of growth. The production of engines more than doubled in the 10 years following the deregulation.

Fig. 4 presents the number of engine models produced each year and the number of new engines introduced. As shown by the figure, the number of products sharply increased during the 1980s.

Major turboprop manufacturers introduced large technical improvements in cruising speed, rate of climb, payload and baggage capacity, along with a reduction in cabin noise levels. The aircraft with the new performances offered longer range and time of flight.

A number of new turboprop aircraft in the 31–50 range entered into service, including the ATR42, de Havilland Dash 8, Fokker 50, Saab 340 and Embraer Brasilia. Some turboprop aircraft were introduced in the segment of 51–90 seats previously totally operated by the jet. At the same time new small jets in the larger seater range emerged, including the BAE 146. There had also been expansion in the 19-seat sector, fuelled mainly by the growth of US feeder airlines operating into the major carriers’ hubs.

Until the 1990s, the 31–50 and <30 seat segments of the market had been the niche for the turboprop driven aircraft. However in 1992 Canadair introduced a 50-seat regional jet, Embraer the 30–50 seat ERJ and Fairchild Dornier the 328 and 428 JET.

During the 1990s the regional aircraft market has undergone a new radical change. The market has shifted, this time irreversibly, from turboprop to turbofan, and supply of turboprops has currently to face a dramatically reduced demand (Schaffler, 1991; Norris, 1997a,b; Lewis and Warwick, 1998; O’Toole, 1998; US International Trade Commission, 1998; Kingsley-Jones, 1999b). The process of technological substitution is leading to a structural decline of the turboprop industry, characterised by a reduction of orders see Fig. 3, by a process of reconversion to the jet technology undertaken by turboprop manufacturers, by the birth of joint development programs (Barrie et al., 1997; Moxon, 1998; Doyle, 1999a), and by exit of some airframe producers such as Saab and Fokker (Kingsley-Jones, 1998). Embraer and Dornier (now controlled by Fairchild) announced plans for the launch of a family of jets in the 70–100 seat range, while Alenia tried to develop the ATR turboprop family into a new, larger regional jet. Joint ventures with British Aerospace and Chinese manufacturers eventually failed. In spring 2000, Alenia signed an agreement with Aerospatiale, DASA and CASA for developing civil and military programmes. At the end of this conversion process, the remaining competitors will only supply small jets.

4.2. The structural evolution of the turboprop engine industry

The structure and dynamics of the turboprop engine industry are analysed by looking at the pattern of entry and exit of engine manufacturers, the level of concentration and the dynamics of market share.

The industry is composed of a small number of players. Since its birth, the industry has counted only nine engine manufacturers.5 Fig. 5 shows the evolution of the number of firms and the pattern of entry and exit. The peak number of firms competing at the same time is seven, and this occurred during the 1980s, when the industry registered high rates of development.

The pioneer was Rolls Royce, followed by Allison in 1955. During the 1960s and the 1970s major companies such as Pratt & Whitney, General Electric, Turbomeca and Garrett entered the industry. The 1980s were characterised by the entry of minor companies, including Dongan, Walter and Lycoming. Allison exited from the industry in 1969 and entered again in 1992.

By 1997 the industry was composed of five actors. Minor companies exited during the 1980s, following their customers. All major players, except the former leader Rolls Royce, survive in the market.6 This pattern does not conform with the predictions of the traditional industry life cycle models. The turboprop engine industry does not experience a shakeout during its evolution, as five out of seven companies remain active in 1997. Furthermore, the reduction in the number of players that started in the 1990s can be considered a part of the process of

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5 The name of companies and their entry and exit date are reported in Appendix A and B.
6 After the financial crisis of the 1970s, Rolls Royce concentrated its efforts only in the jet market and did not introduce products with the new technology in the turboprop industry. This caused its exit from the market in 1988.
The progressive disappearance of the industry, due to the technological substitution with the jet, and not the effect of internal dynamics.

Fig. 6 describes the evolution over time of the level of industrial concentration, as measured by the CR2 and the Herfindahl index. The turboprop industry shows a slightly oscillating level of concentration. Both indexes conform to these patterns. CR2 clearly marks the end of a duopolistic industry structure in 1963 and the entry of new firms. The level of the CR2 index stays high, implying that the market continues to be concentrated around two actors even after new firms enter the industry.

The dynamics of market shares underlying the process of concentration are shown in Figs. 6 and 7.

The figure shows the continuous reduction of market share of the former leader Rolls Royce, which exits from the market, and the substitution by the new leader Pratt & Whitney. The market is always characterised by the presence of a strong leader, and by a few companies with rather unstable market share dynamics.

We observe that, in the first half of the period, the level of concentration shows a decreasing pattern as the leader loses market share, due to the entry of large competitors. As Pratt & Whitney enlarges its market share and becomes the leader, the industry concentration starts to increase. During the 1980s the entry of new firms causes a reduction of the Herfindahl index. It increases again as minor companies exit from the industry and the leader expands its market share.

By 1997 the industry was highly concentrated, as the CR2 stood at 0.8 and the leader supplied 70% of the total market.

This pattern can be discussed as a special case of non-shakeout in the industry evolution, characterised by a high level of concentration, the presence of a strong leader, but at the same time the survival of almost all smaller companies in the market.

5. Explaining the non-shakeout pattern

The case history discussed in the previous sections is remarkable in that it shows an evolutionary pattern in which the presence of a dominant leader and the high concentration does not involve the exit
of competitors, but rather a stable coexistence between incumbents and entrants.

The explanation of this evolutionary pattern must address several factors on the demand and the cost structure sides. On the demand side we consider segmentation of the market and sourcing strategies of customers. On the supply cost-structure side we analyse the level of economies of scope.

5.1. Demand segmentation

The structure of demand, represented by the turboprop aircraft manufacturers, is characterised by several distinctive factors. Differences between the prop and jet aircraft industries help in understanding the peculiarity of this industry.

First of all, the total number of turboprop manufacturers is quite large with respect to the jet industry (22 over the entire life of the industry, 11 still active in 1997).

Second, aircraft manufacturers in the turboprop industry are not the same as in the jet industry. Neither Boeing and McDonnell Douglas, nor Airbus, have ever been active players in the turboprop sector after the emergence of jet technology. They recently entered in the upper segment of the small aircraft market, but with jet aircraft (the B717 and the A318, respectively) (Norris, 1998; Jeziorski, 1998a,b; Doyle, 1999b). Only Lockheed entered at different periods in the turboprop (1957–1963) and in the turbojet (1972–1986) industries. The process of technological substitution is also pushing turboprop manufacturers such as Fairchild Dornier and Embraer to launch small jets (Sarathy, 1985; Frischtak, 1994; Norris, 1997c; Jeziorski, 1998).

Thirdly, however, the group of turboprop aircraft manufacturers includes large competitors as well. Some of them (e.g. Aerospatiale producing the ATR with Alenia, British Aerospace producing the ATP) are among the largest aircraft manufacturers in the world and are also deeply involved in the manufacturing of large transport aircraft and of military aircraft. Their strategy is one of global competitiveness, normally through the opening of strategic alliances with different partners in various areas of business. Therefore the structure of demand cannot be explained, in general, by referring to the small size or financial weakness of customers.

Finally, customers are aircraft manufacturers that operate mainly in just one segment of the market. Table 1 shows the distribution of companies across seat segments. Out of 22 manufacturers over the life of the industry, 12 were active in one segment, nine in two segments, and just one in three segments. No one covered four segments, including the rapidly disappearing segment of 91–120 seats dominated by the jet technology. If we look at the final structure of the industry, out of 11 still active in 1997, again the largest part (72%) still operate in one segment.

Those that operate in more than one segment developed their models at different dates, with the exception of the joint venture Aerospatiale-Alenia, which developed the ATR 42 in 1984 and the ATR 72 in 1988, following the same commonality strategy which is typical of the jet industry.

Therefore, it is not just the large number and small size of customers that matters. Rather, it is the independence among segments on the customer side (Sutton, 1998). The explanation of this pattern goes beyond the scope of this chapter and is the subject of future work, which will take into consideration the structure and evolution of the airline industry as well. However, it is interesting to note that this is in sharp contrast with the pattern found in the jet aircraft industry (Bonaccorsi, 1996; Sutton, 1998), which is one of decreasing number of large suppliers operating simultaneously in all segments of the jet market. Since large jet aircraft manufacturers operate across all segments and plan their engine acquisition strategies in an integrated manner, they favour complete range suppliers. As a result of this enormous pressure, all large engine suppliers operate in all market segments. The only jet engine suppliers that were able to survive in one or a few segments are those that supplied smaller jet engine manufacturers

Table 1

<table>
<thead>
<tr>
<th>Number of segments</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of companies</td>
<td>12</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Percentage of companies</td>
<td>0.55</td>
<td>0.41</td>
<td>0.05</td>
</tr>
</tbody>
</table>
(e.g. British Aerospace or Embraer), which do not target the large transport aircraft market.

The same pressure is not found in the turboprop industry. Faced with customers that demand engines for just one aircraft size at a time, with no significant interdependence among segments, turboprop engine suppliers could survive with a limited range of products.

5.2. Sourcing strategies

Another important characteristic of the demand for turboprop engines is that it takes place within an almost generalised single-sourcing strategy. By single sourcing we mean that aircraft manufacturers select just one engine supplier for each new programme, possibly by asking the same manufacturer to develop several versions of the basic engine for the corresponding versions of the aircraft programme. This pattern is in sharp contrast with the one found in the jet engine industry, in which aircraft manufacturers started to integrate several engines on the same programme or even, in some limited cases, on the same version.

There are several reasons explaining single-sourcing strategies of aircraft manufacturers. Firstly, in the turboprop industry there is no strong pressure from airlines for having multi-engined aircraft. In fact, airlines operating jet aircraft exert a powerful influence on the selection of the engines. Since airlines operate across many seat-range segments, their costs (mainly for maintenance and pilot training) are heavily influenced by the diversity of both aircraft and engines. By pushing towards multiple sourcing of engines on the same aircraft model, they gain flexibility in selecting engines that are consistent with previous aircraft models, even from other manufacturers, and try to minimise their costs across the whole fleet. On the contrary, airlines operating turboprop aircraft often have a small fleet of similar models. Their influence on the selection of engines is very weak. Secondly, the price of turboprop aircraft is much lower than the jet. The cost of integrating two or more different engines on the same version of a turboprop aircraft is too large with respect to the final value of the product.

Figs. 8 and 9 shows the sourcing strategies of aircraft manufacturers by identity of engine suppliers across all aircraft programs. Out of 22 aircraft manufacturers, 10 operate using multiple sourcing and 12 with single sourcing. It is also evident from Fig. 9 that companies operating with dual sourcing still

Note: The name of aircraft programs are reported in Appendix 2.

Fig. 8. Turboprop aircraft companies operating in multiple sourcing.
equip the aircraft program through single sourcing. There are just three cases in which the same aircraft has been equipped with engines produced by different companies.

The first is the Convair 580/640, launched in 1960 with an Allison 501 engine and then re-equipped with a Rolls Royce Dart. The Let 41 was developed by the Czech producer Let with an Eastern-made Walter engine; then it was powered by a Pratt & Whitney engine, but only 10 units of this configuration were sold. Finally, the Nord Aviation 262 was equipped with a Turbomeca and a Pratt & Whitney.

As is clear from these examples, multiple-sourcing strategies are quite rare in the industry. A similar pattern applies even at the level of individual companies. At this level a single-sourcing strategy is much less justified from an economic point of view. Multi-product companies have the incentive to put their existing suppliers under pressure, by using other suppliers in different lines of products and intensifying competition against one another. The incentive to carry out this strategy is a function of the ratio between the expected benefits and the incremental costs associated with managing a new supply relation. But in a highly competitive market the incremental costs may well be absorbed by the new supplier, which may be keen to enter into the purchasing structure of a large customer. Under many situations, a strategy of parallel sourcing (Richardson, 1993) is optimal. Nevertheless, turboprop manufacturers tend to stick to their existing suppliers.

The impact of single sourcing on the structural dynamics of the engine industry is very important, since this strategy tends to protect the market share of engine suppliers over time, depending on the dynamics of sales of aircraft. Basically, the adoption of single-sourcing strategies on the demand side means that specialist strategies of suppliers can survive more easily.

In the commercial jet industry, aircraft are built to accept any one of several turbine configurations offered. This trend led to the shift from single to dual and multiple sourcing strategies of aircraft manufacturers. Alternative sourcing provided advantages through the development of competition among suppliers, gave better information about suppliers' cost and performance capabilities and increased the opportunity for innovation. It also created an insurance policy for cases of demand peaks, particularly important in an industry characterised by discontinuous demand. However, dual or multiple sourcing is only possible when high suppliers' up-front costs can be recovered over large volumes (see for other industries Asanuma, 1985; Sako, 1992).

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Some scholars analysed the pros and cons of sole, dual and multiple sourcing, most of them to explain the defence procurement process (Demski et al., 1987; Riordan and Sappington, 1989; Anton and Yao, 1987, 1989, 1992; Baily and Farmer, 1982).
5.3. Economies of scope

While the independence of submarkets implies that there are not strong advantages in pursuing a dominant multi-market strategy, it is clear from our discussion in the first part of the paper that this is not a sufficient condition for a non-shakeout pattern of industry evolution. We now turn to the cost structure of turboprop manufacturers and try to collect evidence on the existence of economies of scope.

The collection of cost data in the commercial aircraft industry (in both the engine and airframe sectors) is, however, an almost impossible task. While in the military sector the very structure of procurement contracts forced defence contractors to make publicly available extremely detailed cost data, some of which have also been the object of published econometric analysis (Alchian, 1963; Marschak et al., 1967; Large et al., 1974, 1976), this does not apply at all to the commercial sector. Published papers based on detailed cost data in either the jet or the turboprop commercial aircraft industries are very rare.

We therefore must look for indirect measures of economies of scope. We have been able to build an indirect measure which is, in our view, reasonably unambiguous and accurate. In the design and manufacturing of airframe and engine products, the most effective way to exploit economies of scope is to utilise the same basic version as a bottom line for developing a family of products. It is also possible to obtain economies of scale by maximising the commonality of components across versions and planning the utilisation of a larger capacity.

In the design of jet aircraft this is made by lengthening the fuselage without changing the diameter of the section and the basic design of the wing area (Mowery and Rosenberg, 1982). The design of jet engines is increasingly based on the concept of ‘robust design’ (Rothwell and Gardiner, 1989, 1990). Robustness occurs in terms of adaptability of the basic design to different customers and to different market segments. It allows some degree of economies of scale and scope on the production side and offers the possibility of enhanced learning from user experience. In fact users, working with similar platforms, can be more apt to ask for specific modifications of design.

The development of a family is normally not enough for serving different segments, but it helps in filling each segment with slightly different products that better fit into the requirement of airlines. In some cases (e.g. the A320 and A321 or the various versions of B727 and B747) it is possible to use the same design to address different segments. Large savings can be made in design costs and in the tooling of equipment.

If economies of scope were really important at either R&D or manufacturing level in the turboprop engine industry, then we would find that manufacturers develop several versions of their basic product design.

We build a simple indicator at the product level which provides the basis for assuming the presence of economies of scale and scope. We compute the average number of engine versions per engine program. This represents a measure of the degree of robustness of basic designs (programs), which indicates the presence of economies of scale and scope in design and manufacturing activities of engine companies, as dependent on the extension of product families.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Number of versions per program in the jet and turboprop industries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jet engine</td>
</tr>
<tr>
<td>Number of programs</td>
<td>21</td>
</tr>
<tr>
<td>Number of versions</td>
<td>120</td>
</tr>
<tr>
<td>Average number of versions per program</td>
<td>5.71</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>4.94</td>
</tr>
<tr>
<td>Maximum</td>
<td>16</td>
</tr>
</tbody>
</table>
The comparison between jet and prop aircraft and engine industries represents a benchmark for evaluating and interpreting the data on the turboprop engine industry.

Table 2 shows data on average, standard deviation and maximum number of versions per program in the turbojet and turboprop industry. The average numbers are 2.41 in the turboprop engine and 5.71 in the jet engine, respectively. The average and the maximum number of versions per program in the jet is higher than in the prop, both in aircraft and engine. As the distribution of the values is not normal, the \( t \)-test for the equality of means is not valid. We carried out the Mann–Whitney U-test of two independent samples, for each couple of means. The means of jet engine and prop engine resulted significantly different at the level of 1%.

In addition, the number of programs in turboprop is higher than in turbojet, although the size of the market is smaller. This suggests that the turboprop market is more fragmented in different programs and that the degree of economies of scale and scope is much lower. In the jet, given the heterogeneity of technical and market characteristics of different programs, economies of scale and scope are obtained by introducing subsequent versions of the same program, more than by developing many programs. The higher standard deviation in the jet industries also indicates a more disperse distribution of the number of versions per program, motivated by the presence of a number of ‘robust’ programs with many versions, and of a few programs, mainly in the regional jet market, with only one or two versions.

It is evident that the turboprop technology does not lend itself to processes of extensions of product families based on the exploitation of shared design knowledge. Economies of scope do not appear to matter very much.

### 5.4. Industrial structure and dynamics

As a result of the factors discussed above, the structure of the industry is composed of several quasi-independent sub-markets (segments), with weak linkages on both demand and supply sides. The turboprop industry is an interesting case of non-shakeout, since it shows at the same time a tremendous process of concentration and the preservation of conditions for the survival of smaller competitors.

It is our contention that the factors discussed in previous sections are sufficient to explain the evolutionary pattern found in this industry. The stylised facts that are found in the long-term industrial dynamics can be formulated as follows.

- The industry has been systematically marked by a high degree of concentration.
- The distribution of market shares has systematically seen the presence of a dominant leader, with a turnover between the early leader and a new entrant.
- There is strong market concentration without shakeout.

The following analysis will show these facts.

- The leader follows a strategy of coverage of all market segments (generalist strategy).
- Contrary to expectations, followers do not imitate such a strategy but survive by competing in one or a few segments each (specialist strategy).
- As a result there is a coexistence of strong leader dominance and specialist strategies, which results in high concentration without shakeout.

This pattern is different from the one discussed by Phillips et al. (1994) with respect to business jets. In that case only specialist players operate in the industry, due to deep differences in customer requirements within and between segments. In the turboprop engine industry, on the contrary, we find the coexistence of a global leader operating in all segments and of smaller players specialising in just one segment.

If our explanation is correct, then in the turboprop industry there are no inherent advantages in pursuing a generalist strategy over a specialist one. Since this conjecture does not lend itself to direct testing, we offer two indirect strategies for corroborating it, by using a contrario arguments.

First of all, if these advantages were present, then the current industry configuration would not be stable, since there should be competitors that try to imitate the leader by filling all market segments and
trying to increase their market share. We should expect other competitors to follow the escalation of Pratt & Whitney across market segments. Note again that this is exactly the strategy pursued by engine manufacturers in the jet industry, in which Rolls Royce, Pratt & Whitney and General Electric all offer products over the entire range of market segments. Therefore a natural (although indirect) test of the conjecture runs as follows: look at the distribution of competitors by number of market segments they serve and identify elements of instability in the industry configuration.

Second, if these advantages were intrinsic to the turboprop technology and/or market, then the strategy of filling all market segments would have been pursued by the leader since the beginning of its life. While admitting that some time is needed to develop new products for different market segments, we would expect the leader to exhibit a clear pattern of product line extension during, say, the first 10 years of its life in the industry. Note in addition that the evolution of turboprop technology has not seen significant discontinuities during the whole industry lifetime.

The distribution of market shares confirms this analysis. Fig. 10 shows wildly fluctuating market shares, with the initial leader (Rolls Royce) gradually loosing ground and the new leader (Pratt & Whitney) gaining a large share in all markets. However, specialist players are still able to capture important

Fig. 10. Distribution of market shares by seat segment.
shares of their respective markets. While the aggregate distribution suggests a pattern of dominance of the leader, the distribution by market segments reveals a different picture. Pratt & Whitney is still the dominant player in all three segments, but the second competitor now has a significant market share. The dominance of the market at the aggregate level is the result of the disproportionate growth of the three market segments. In particular, the segment for small aircraft (less than 30 seats) is the only one which is not subject to technological substitution by the jet technology, and has grown much more than the others.

We can summarise the structure of the industry at the level of segments. Out of nine engine manufacturers, six operate in just one segment, one in two segments and two in all three segments. The latter are the two leaders, Rolls Royce and Pratt & Whitney. Note, however, that in the case of Rolls Royce just two segments were really covered, since the third one (91–120 seats) existed for just a few years before being swept away by technological substitution. Rolls Royce never entered the very small aircraft segment (less than 30 seats), which instead was the starting point for Pratt & Whitney.

It is clear from our data that there is no evidence at all of a pattern of imitation of the leader escalation strategy by other competitors. Each of them, with the exception of Allison, survives in just one segment. Based on this evidence, we conclude that the industry configuration is rather stable, and find initial support for the conjecture that there are not overwhelming advantages in pursuing a generalist strategy.

The stability of the configuration is also based on the sourcing strategies of aircraft manufacturers. Specialist suppliers were able to survive and preserve important market shares as they represented the only supplier of aircraft programs in each market segment. While cases of dual sourcing are observed at the company level, they do not occur at the segment and the program level. Ideally, the market is fragmented at the program level. Each engine manufacturer enters to supply anew aircraft manufacturer and entry in a new segment is always associated with the introduction of a new aircraft program. We showed only three short-lasting cases of dual sourcing at the program level, and only one of them ended up with a substitution of the supplier. Moreover, exit of suppliers occurred especially during the phase of decline of the turboprop industry, due to exit of their customers.

This suggests that once a supplier gains a market, it is difficult to destabilise its position, and its market share depends on the success of the program and on the number of customers/programs it serves.

The second indirect test requires a longitudinal analysis. We carried out this task by reconstructing the entry decisions of the leader in each market segment, by tracking the initial year of supply to all new programmes since its birth in the industry (with new or existing engine products). Interestingly, we are able to compare the pattern with the one that the same firm — Pratt & Whitney — generated through its entry decisions in the jet engine industry. By controlling for firm-specific factors we are able to offer a very powerful support for the conjecture.

Fig. 11 shows the time pattern of entry of Pratt & Whitney in all segments of the two markets. The dark line describes the pattern in the jet industry, while the bright line the pattern in the turboprop. The path is defined by the first supply of a Pratt & Whitney engine to an aircraft program, classified by seat-segment. The dashed line indicates the presence in the seat-segment after the first entry. The pattern in the jet and in the turboprop is astonishingly different. In the jet engine industry, Pratt & Whitney followed all requests from Boeing and Douglas since the very beginning of its life, and entered many different segments in a few years. After 10 years of life it was already active in four segments (three, if we exclude the short experience with the French Caravelle in the 51–90 seat segment). In 1969 it entered the very large (more than 400-seat) segment by supplying the Boeing 747, and in 1970 it added the 310–399 seat segment. In its entire life cycle, no segment was missed. Note that even the very low segment of less than 30 seats has been recently addressed, with the decision to equip the Fairchild Dornier 328JET. In short, in the jet engine industry Pratt & Whitney immediately and consistently followed a strategy of multi-segment coverage, by satisfying any requests from large aircraft manufacturers.

This is in sharp contrast to the strategy pursued in the turboprop industry. Here Pratt & Whitney en-
entered in 1965 in the small aircraft segment (less than 30 seat), supplying de Havilland Canada. After that, it addressed the same market for all its life, adding many new customers in the same segment. It was only in 1978 that it entered the 31–50 seat market by supplying the DHC7, following the strategy of extension of the product family of the customer de Havilland Canada. In 1984 it supplied the ATR consortium with an engine for the new ATR 42. A few years later it entered the large 51–90 seat segment with the ATR 72. Therefore the strategy of market dominance through multi-segment coverage has not been pursued since the beginning, but very late in its life history.

It is interesting to note that the decisions to enter new segments have been somewhat the effect of contingent factors. The entry in the 31–50 seat segment, in fact, was due to the stretching of the DHC aircraft program and in 1984 to the sudden opening of rich market opportunities with the newly launched ATR 42. Both ATR partners (Aerospatiale and Alenia) were pursuing a strategy of extending to the turboprop market some of the standard practices they experienced in the jet market, and looked for a large turboprop engine supplier. At that time Rolls Royce was leaving the turboprop market. The only strong competitor at the beginning of the 1980s was General Electric, which was present in the 31–50 seat market supplying De Havilland, CASA and Saab.

The acquisition of the ATR orders opened the way to replace Rolls Royce in supplying Fokker which was launching the new F50 in the 31–50 range, consolidating the breakthrough. Finally, the decision to enter the large 51–90 seat segment was just the result of the need to follow the ATR consortium in the successful effort to ‘import’ jet technology practices into the turboprop industry by stretching the ATR 42 into the larger ATR 72. In some sense, Pratt & Whitney was pulled to extend its market coverage. As is clear from this discussion, the longitudinal test shows that, controlling for firm-specific factors, there is a sharp difference between the jet and turboprop engine industries in the pattern of market coverage pursued by the market leader. The same firm behaves in dramatically different ways in the two markets. We find evidence of strong underlying differences in the advantages of market dominance strategies.

Taken together, the two tests strongly support the conjecture that there are no overwhelming advan-
tages in following a generalist strategy in this industry. This is a sufficient explanation for the pattern of market concentration without shakeout.

6. Conclusions

In this paper we have tried to rationalise the main results of research on anomalies in the life cycle of industries. A simple categorisation was proposed, according to which all anomalies can be explained by referring either to the discontinuity in the regime of appropriability (mainly brought about by changes in the division of labour across the industry) or to the lack of increasing returns in some stages of firms’ activities. The outcome of the long-term evolution of industries which do not conform to the standard ILC pattern depends on the interplay between these factors and therefore must be subject to empirical appreciation and analysis.

In addition to this conceptual contribution, we have shown a detailed industry case study which exhibit a very interesting pattern of long-term evolution, marked by a high level of concentration and a continuous presence of a dominant leader, without shakeout. We have explained this pattern by showing the stable coexistence of generalist and specialist strategies in the same industry and identifying the causal factors. These lie in the lack of increasing returns (economies of scope) in marketing activities, due to high market fragmentation and strong independence of submarkets, and in the lack of increasing returns of the same kind in R&D and manufacturing, due to the nature of turboprop technology. Therefore our case study falls neatly in the second class of anomalies with respect to ILC predictions illustrated in a previous work. However, we add to the literature by insisting that both market demand and cost structures have to be investigated in order to predict non-shakeout outcomes.

More precisely, demand factors such as deep market segmentation and single or (at most) dual sourcing strategies of customers, and cost structure conditions such as lack of significant increasing returns in R&D and manufacturing prevent the shakeout from taking place.

Our analysis sheds some light on the long-term evolution of those industries that do not conform closely to the predictions of the ILC model. Among these, there are many non-mass production industries that design and manufacture complex systemic products. In these industries both market and technology conditions point to the lack of increasing returns deriving from scale and scope.

Demand discontinuity, heterogeneity and customisation imply that there are no economies of scope in serving different customers. Each market segment (at the limit, each individual customer) requires careful interpretation of specific needs and strong investments into customer interface.

Small batch production, general purpose manufacturing technologies and made to custom product development also imply that there are not significant economies of scope in R&D and manufacturing. Very often the manufacturing process is designed jointly with the product (at least in tooling), so that also economies of scale are difficult to reach.

Insofar as these characteristics are present in complex system industries, there are good reasons to expect that a non-shakeout pattern is likely to emerge.

Acknowledgements

We thank Keith Pavitt, Ed Steinmueller and Nick von Tunzelmann and anonymous referees for precious comments on earlier versions of the paper. The financial support of the Italian Ministry of Research (MURST 40% — ‘Industrial dynamics and interfirm relations’) is gratefully acknowledged.

Appendix A. Engine suppliers, entry and exit date

<table>
<thead>
<tr>
<th>Engine manufacturer</th>
<th>Entry date</th>
<th>Exit date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allison</td>
<td>1955</td>
<td>1969</td>
</tr>
<tr>
<td>Allison</td>
<td>1992</td>
<td>—</td>
</tr>
<tr>
<td>Dongan</td>
<td>1984</td>
<td>1991</td>
</tr>
<tr>
<td>Garrett</td>
<td>1974</td>
<td>—</td>
</tr>
<tr>
<td>General Electric</td>
<td>1965</td>
<td>—</td>
</tr>
<tr>
<td>Lycoming</td>
<td>1973</td>
<td>1996</td>
</tr>
<tr>
<td>Pratt &amp; Whitney</td>
<td>1965</td>
<td>—</td>
</tr>
<tr>
<td>Rolls Royce</td>
<td>1948</td>
<td>—</td>
</tr>
<tr>
<td>Turbomeca</td>
<td>1964</td>
<td>1976</td>
</tr>
<tr>
<td>Walter</td>
<td>1982</td>
<td>1995</td>
</tr>
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Appendix B. List of aircraft programs

<table>
<thead>
<tr>
<th>Code</th>
<th>Aircraft</th>
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<td>ATP</td>
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<tr>
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<td>ATR42</td>
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<tr>
<td>BE1900</td>
<td>Beech 1900</td>
</tr>
<tr>
<td>C212</td>
<td>CASA/IPTN 212</td>
</tr>
<tr>
<td>CN35</td>
<td>CASA/IPTN 235</td>
</tr>
<tr>
<td>CV24</td>
<td>Convair 600</td>
</tr>
<tr>
<td>CV34</td>
<td>Convair 580/640</td>
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<tr>
<td>Do228</td>
<td>Dornier 228</td>
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<tr>
<td>Do328</td>
<td>Dornier 328</td>
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<tr>
<td>DHC5</td>
<td>DHC-5</td>
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<td>DHC-6</td>
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<td>DHC-8</td>
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<td>F27</td>
<td>Fokker F27</td>
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<tr>
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