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Patterns of Learning in Dynamic Technological System Lifecycles—What Automotive Managers Can Learn from the Aerospace Industry?

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Abstract: Not only with respect to the common overlaps within the market of urban air mobility, but also in terms of their requirement profile with regard to the systemic core, all mobility industries are converging. This article focuses on the required patterns of learning in order to cope with these changes, and what automotive managers can learn from the aerospace industry in this context. As organizational learning is the central parameter of economic evolution, and technology develops over trajectory shifts, companies are, at the very least, cyclically forced to learn ambidextrously, or are squeezed out of the market. They have to act and react as complex adaptive systems in their changing environment. Especially in these dynamics, ambidextrous learning is identified to be a conditio sine qua non for organizational success. Especially the combination of efficiency-oriented internal exploitation with an explorative and external-oriented open innovation network turns out to be a superior strategy. By combining patent data, patent citation analysis and data on the European Framework Programs, we show that there are temporal differences, i.e., position of the product in the product, technique, technology, and industry life cycle. Furthermore, we draw a conclusion dependent on the systemic product character, which enforces different learning requirements concerning supply chain position and, as an overarching conclusion, we identify product structure to be decisive for how organizational learning should be styled.

Keywords: ambidexterity; technological learning; open innovation; complex product systems; technological evolution; industry evolution; knowledge evolution; industry convergence; automotive; aerospace

1. Introduction

As techniques are growing in technological complexity over time, the evidence of learning as a success factor for organizations is growing, as they have to act and react as complex adaptive systems in their environment. Not only with respect to the common overlaps within the market of urban air mobility [1], but also in terms of their requirement profile with regard to the systemic core, all mobility industries are moving ever closer to one another, i.e., industrial and technological convergence is a much-debated topic. However, industrial convergence is not to be seen in terms of its balancing products and overlapping customer markets, but rather in the technological requirement profiles of organizations. While the aerospace industry can be described quite early in its development as a system of complex products, this is a recent phenomenon for the automotive industry. Autonomous mobility, electrification of powertrain and connectivity result in complex automotive product systems whose handling places the ability to be ambidextrous at the center of the entrepreneurial capability spectrum. Organizations have to widen and deepen their knowledge bases to cope with such dynamics. However, what factors do managers have to recognize? Which of them are decisive when evaluating how the organization has to learn? Is there the possibility to generalize for all organizations or does one have to differentiate temporally and according to supply chain position? Especially in dynamic environments, ambidextrous learning is identified to be a conditio sine qua non for organizational success. However, what factors decide which tangible learning requirements are imposed on organizations? We identify the product and industry structure, as well as cycle stages of technology, product and industry as the factors to be recognized. Therefore, we analyze learning requirements on a three-scale level. First, we show that there are temporal differences, i.e., position of the product in the product, technique, technology, and industry life cycles. Second, as a conclusion of the systemic product character, there are different learning requirements concerning supply chain position; and third, as an overarching conclusion, we identify product structure to be decisive for how organizational learning should to be styled.

2. Materials and Methods

We used data and measurements in a threefold manner: patent data, patent citation analysis and data on the European Framework Programs.

To get information on how the automotive industry develops over time with respect to learning requirements, we used patent application data. On the one hand, we analyzed the learning behavior of one exemplary automobile manufacturer (Daimler AG) with respect to conventional and electrified powertrain technology, where the first represents a field of exploitation, and second a field of exploration. For this purpose, we used a data set that included all applications of the manufacturer in the years 1991, 2001 and 2011 that were registered at the German Patent Office (DPMA). The allocation of the applications to conventional and electrified powertrain technology is done by a combination of the International Patent Classification (IPC) and an identification of keywords [2]. On the other hand, we studied learning behavior at the global automotive industry level covering a period from 1980 to 2011 in the German (DPMA), Japanese (JPO) and US-American (USPTO) Patent Offices. As progress in the fields of battery and fuel cell technology is a proven key factor of future success within this sector, we set a technological focus on the related subclasses of the IPC [2]. The overall composition of the patent data set includes 58.875 applications for battery technology and 59.628 applications for fuel cell technology. For the identification of automotive OEM and suppliers, we reviewed the company structure of the 30 biggest OEM and 100 biggest suppliers globally in order to capture all relevant patent applications, even of the subsidiaries. Comprehensive and detailed information on the selection, gathering, processing and composition of the automotive data set and evaluation methods can be reviewed at Knappe [2].

To get information on how the aerospace industry develops over time and with respect to learning requirements, we used data on the European Framework Programs (FPs) on Research and Technological Development and patent data. To identify exploration and exploitation for Airbus S.A.S. we used patent citation analysis. The database is the OECD patent and citation database. We defined explorative patents as those not citing any others and exploitative patents as those citing other patents. Using the EUPRO database, Guffarth and Barber [3,4] constructed a network for each FP based on collaborative aerospace projects. We used this data to obtain a classification of the three forms of learning. Therefore, we investigate whether actors take part in explorative or exploitative projects by inspecting all aerospace-related projects [1]. If actors are involved in both types of project, they are considered to be ambidextrous. If not, they are classified to be either exploitative or explorative learning actors in the network. The allocation to a certain supply chain level was done based on expertise, and detailed information on selection, gathering, processing and composition of the aerospace data set can be reviewed in Guffarth [1].

3. Learning and Organizational Knowledge Bases

Due to its interdisciplinary nature, knowledge has to be treated carefully. In an economic context we define knowledge as composition of information which is person- or organization-related, specific and target-oriented [5]. So knowledge is based on information which is processed, reflected and internalized [6]. Its absorption and acquisition is preceded by a learning process, whereby it is dependent on prior or existing knowledge. So learning is defined as a process and knowledge as a result of it [7]. There are several features that are inherent in knowledge: It can be explicit and global or tacit and local [7–10]. In particular, the transformation of (objective) information into (subjective) knowledge is crucial, as this process has different paths influencing developments and implications for market evolution [11]. Further, we differentiate between individual and collective knowledge, which is crucial for the definition of organizational knowledge that is composed out of the individual knowledge of the employees and the collective knowledge of the organization, where joint behavioral patterns are embedded in the culture and forms a network of relationships [12]. Based on the concept of bounded rationality, Witt emphasizes the conception of a socially shaped, tacit cognitive frame, which emerges and underlies any entrepreneurial venture and which could only be realized with difficulty by ordinary market exchange relations [13]. Taken together, this forms the knowledge base of the organization [14]. As knowledge can be generated within the organization or be developed through external relations, the organization needs the ability to absorb new knowledge, i.e., the absorptive capacity [11,14–17]. As own knowledge can be seen as a prerequisite for the absorption of new knowledge, absorptive capacity is the result of, as well as the requirement for, organizational learning from outside [9,15]. As Chesbrough depicts with the concept of open innovation, the access to external knowledge and capabilities can essentially improve the innovation process [18,19]. A widening of this perspective is provided by the dynamic capability approach, which puts an emphasis on the long-term competition advantage for organizations that results from the adaptability of their competences that is generated through dynamic organizational routines [20–22]. The responsiveness of an organization to dynamics in its environment is seen as a critical success factor whereby the ability to adapt, integrate and reconfigure internal and external knowledge and resources are in focus [20–22]. While in stable environments the establishment of routines and experience-based decision-making are paramount, flexible and quick generation of required knowledge is decisive in dynamic environments [23]. In consequence, knowledge generation is a prerequisite for permanent adaption of the organizational knowledge base in dynamic environments, and therefore a prerequisite for organizational success [24,25]. In principle, there are two strategies to advance and enlarge the organizational knowledge base, these are: exploitation of existing knowledge, and exploration of new knowledge [26,27]. Exploitation is associated with terms like improvement, efficiency, selection and implementation, and therefore encompasses usage, commercialization, enhancement and refinement of existing knowledge, whereby an increased focus is on routines, standardization and cost reduction [15,26,28–30]. Expected returns within this pattern of learning are positive and predictable in the short term [26]. However, in the long term, a pure focus on exploitation of existing knowledge brings the risk of the knowledge base drying up due to the cumulative and path-dependent character of knowledge, which might lead to lock-ins [31,32]. To avoid this threat, organizations have to access new knowledge fields. This learning strategy is denoted as exploration. Therefore, exploration is connoted with terms like search, variation, flexibility and discovery [26]. In the context of bounded rationality, especially firms that are forced to continuously create new businesses cannot be operated with standardized and routine-led plans based on the fiction that all possible contingencies can be anticipated [13]. A resource allocation to explorative processes detracts from short-term organizational returns, but can open thus-far unknown and uncertain possibilities [29].

4. Technological Systems and Dynamics

To differentiate organizational learning requirements, we conceive of products as systems. Those systems are composed of different subsystems and technologies [33]. Hereby, we emphasize the difference between technology and technique, which are often used synonymously [9]. We define technology as knowledge, including skills and competencies concerning scientific contexts for technical problems [2,34]. As such, technique is the implementation of technology in products and processes [35,36]. Therefore, technique always includes technology, but not vice versa [2]. The additive character of technique is, then, a distinguishing feature of products and opens up a continuum of possible complexity levels that help to classify products on a continuum from simple to complex [37,38]. To make our point here, we differentiate three examples: simple products, products of multiple subsystems in which one is dominant, and complex products (see Figure 1).

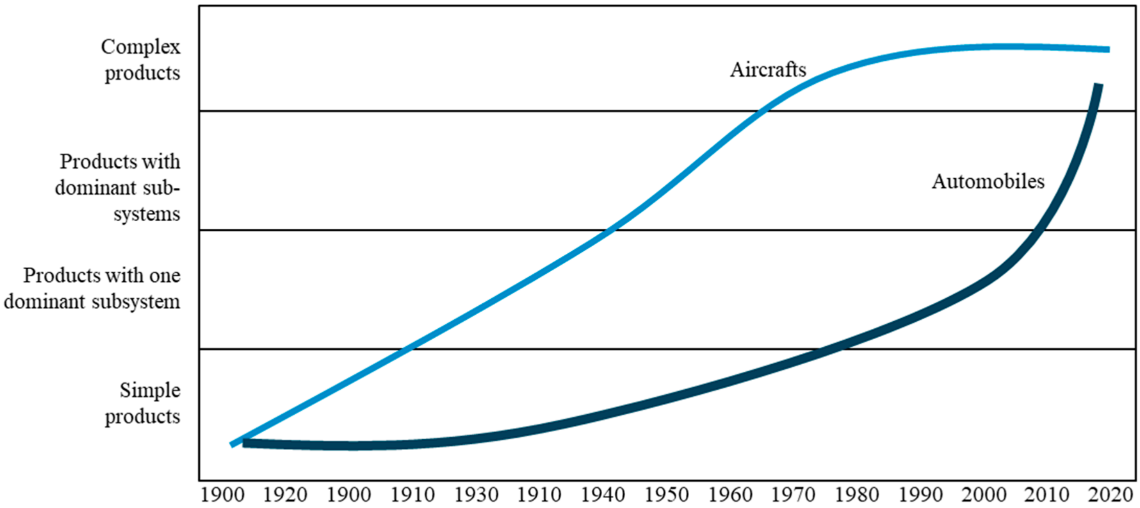

Figure 1. Continuum of product complexity—automobiles and aircraft as references.

Where simple products consist of only one component, e.g., pins, complex products are composed out of numerous elements, components and subsystems which are ordered in a hierarchical manner, and the functions of which interact with and are dependent on each other, as well as the architecture of the entire system [39–42]. Nevertheless, products are transformable. In this respect, two opposing effects are decisive [34]. On the one hand, product complexity increases over time due to functional and technological expansion [38]. On the other hand, organizations try to reduce complexity through standardization and modularization efforts, which move like a wave through the products, so that in the first instance subsystems, and later on, components, are affected [38,43].

A possible presentation of product developments are product life cycles, where there are typically three phases to differentiate: emergence, growth and maturity [44]. For simple products or products with one dominant subsystem, there is a direct relationship between the product, technology, technique and industry life cycle stages [2], which offers the possibility of directly assigning learning requirements based on the life cycle stages of the product for the manufacturer. Accepting the premise that technology develops as paradigms on trajectories in which its development is characterized by path dependencies and irreversibility, remaining technological opportunities shrink over time, and at some point, a paradigm change is enforced for environmental and technological reasons [2,9,45–50]. Meanwhile, in product, industry, and technique life cycles, the emerging phase is connected to exploration, growth and maturity phase, implying exploitation. Therefore, there is a one-to-one correlation between life cycle stage and learning type [2]. This does not hold for complex products [34]. The reason for this is that different subsystems are in different and independent life cycle stages, and a direct implication between stages and learning requirements is not valid on the overall system level [38]. For example, while subsystem one is in a growth phase, subsystem two could be in an emerging phase, and subsystem three in a mature phase. That is, the product structure determines the learning requirements in a critical manner, leading not only to the need for a much broader consideration than just focusing on the manufacturer level but to taking different supply chain levels into account, as different organizations of supply chain level have different stages in life cycles. These different learning requirements are discussed in the next subsection.

5. Learning Patterns Due to Technological Complexity and Dynamics

As presented above, organizational learning is dependent on product structure. Therefore, based on technological changes, the adaption potentials with regard to organizational learning and the structural design of the organization are product-specific. For this reason, we analyze learning requirements on a three-scale level. First, we show that there are temporal differences, i.e., the position of the product in the product, technique, technology, and industry life cycles. Second, as a conclusion of the systemic product character, there are different learning requirements concerning supply chain position. Thirdly, as an overarching conclusion, we identify product structure to be decisive for how learning is styled in organizations. In a first step, we investigate different learning types. We identify three main scientific streams of exploration and exploitation research: first, the differentiation between radical and incremental innovation [51–54]; second, organizational adaption and organizational design of efficiency and flexibility [55–63]; and third, strategic management, as well as type and dimension of learning, and its presence and absence in organizations [64–75]. Nevertheless, a strict dichotomy between exploration and exploitation is not possible [76], as there are intermediate forms between the two poles exploration and exploitation [77].

Additionally, there is a connection between the development of explorative and exploitative knowledge, as over time, former explorative knowledge rigidifies through exploitative routines in the organization's knowledge base [77]. This suggests a temporal distinction between the two concepts, as exploitation stands for securing current viability, while exploration is deemed necessary for securing strategic competitiveness [38,58,78]. So how and when do these two learning concepts have to be applied, and how should they be combined [46,53,57,79]? While focus on exploration detracts from short-term success and may lead to failure traps [46,64,80–82], emphasis on exploitation leads to organizational inertia or success traps from a long-term perspective [82]. This emphasizes the role of an organization's environment, as in stable technological surroundings, exploitation is a viable strategy for an organization to improve its competitive situation, while in dynamic technological environments, exploitation leads to a competency trap [82,83]. As a consequence, organizations need the ability to be ambidextrous, i.e., to reach a dynamic balance between explorative and exploitative learning processes [46]. So the resulting question is whether exploration and exploitation, which are orthogonal learning patterns [58], are most effectively exercised simultaneously or sequentially [34]. Taking technological learning into account, with the three typical development phases—inception, growth, maturity—sequential learning requirements, i.e., cyclical balance of exploration and exploitation, with the concentration of the organization primarily on one or the other learning type [73], in an ideal case leads to sequential equilibrium or punctuated equilibria [58,73,84] in focus. This concept is called cyclical ambidexterity [73], where the periodical transition between phases determines the balance between exploration and exploitation [58,83]. Thereby, cycles of exploitation are interrupted by periods of exploration [56,64,85–87]. In light of the concept of the tradeoff, activities of exploration and exploitation are then to be provided with corporate resources only so long as activities belonging to each learning type promise benefits to the organization in excess of those promised by the other type [26,51,88]. This cyclical ambidexterity has great inertia risk [89], as a change from one to the other learning pattern requires a resource-intensive change in organizational structure and culture, which carries a risk of failure [90], directly threatening the existence of the organization. Furthermore, seen from the perspective of the evolution of innovation networks, the formation of such socio-economic networks is a trust-based matter of time. In consequence, short-term strategic change from an explorative network mode to an exploitative and hierarchically dominated mode is not feasible, as network partners would interpret this behavior as opportunistic. Accordingly, a crucial basis for trust-based cooperation is eroded, and so the basis for future cooperation is narrowed. There are different suggestions for how a concrete realization of ambidexterity within an organization can be achieved, where three possibilities are at the forefront: position-based ambidexterity, where exploration and exploitation are located on different hierarchical levels of the organization [75,91,92]; structural ambidexterity, where different teams and locations are used to separate the learning types, including inter-organizational realization [56,64,85–87]; and contextual ambidexterity, where the individual level, i.e., one person, is decisive [79]. We reject the contextual level approach with respect to its practicability, as it is based on the divergent characteristics of knowledge in exploration and exploitation, as well as routine-based knowledge development [38].

Proceeding from these insights, ambidexterity is the skill of organizations to make capabilities dynamic, i.e., a meta-skill, as it is a capacity for dynamic skills, which is primarily a phenomenon related to the conversion needed in dynamic technological environments with frequent and major changes [73]. Nevertheless, there is another dimension on which to differentiate. In addition to the temporal segmentation of phases, especially in complex product industries, where subsystems follow their own cycles, a pure focus on the manufacturer is not enough. We suggest that there are other ambidexterity requirements in different industries, especially for industries with complex products [16], based on the treatment of the industry as a network through which ambidexterity requirements expand down the supply chain over the industry life cycle [38].

Based on the continuum shown in Figure 1, Figure 2 illustrates the interdependence between product complexity and learning patterns within the dynamic of technological systems and subsystems. On the vertical scale, we differentiate between simple and complex products, while we have to keep in mind that this is just a simplified bipolar model of reality, which is characterized by a continuum. The horizontal scale illustrates the technological cycles of systems and subsystems, where inception is linked to an explorative mode of learning, and growth is connected to an exploitative mode of learning. To incorporate the transition to following technological cycles, the saturation phase is combined with the inception phase of the successor technology, which consequently leads to a combination of exploration and exploitation within this stage. For the sake of completeness, we have to mention that a radical change in technology can also occur during the phase of technological growth. Nevertheless, this aspect does not change the insights derived from the model, as it even raises the timely ratio of ambidextrous learning. Furthermore, these dynamics reveal the need to differentiate between the organizational ability to learn ambidextrously and the practical realization of this type of learning. In the following, we focus on the insights in which ambidexterity is visible in organization behavior.

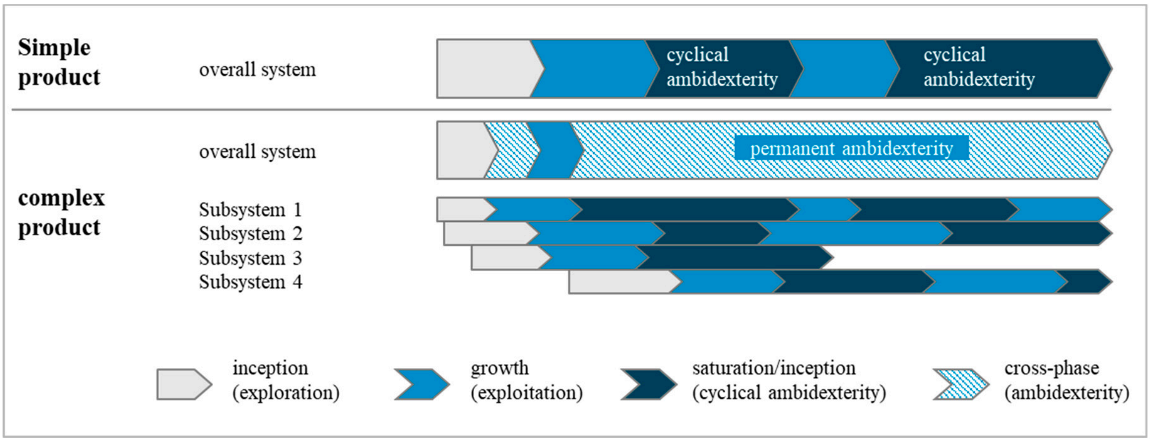

Figure 2. Patterns of technological learning in systems of simple and complex products.

Concerning the illustrated model, we have to distinguish between the initial formation of an industry, including its technological regime, and the transition from a previous technological cycle to its successor. While in the former case the inception phase is characterized by explorative learning alone, the combination of technological saturation and inception leads to ambidextrous learning in the latter case. For simple products, the outcome of this is an explorative pattern during the emergence of an industry, and a periodical changeover between exploitative and ambidextrous learning afterwards, which we call cyclical ambidexterity. Transferring these insights to complex products, we find the described pattern on a subsystem level, while the overall system has to be interpreted as the sum of these subsystems. This means that, after an initial phase of explorative emergence, the progress of the first subsystem to the exploitative phase of growth is likely to enforce ambidextrous learning. Dependent on the degree of system complexity, including the number and technological dynamics of the subsystems, the overall system aspires to the enforcement of permanent ambidexterity, which can only be interrupted by exploitative phases in situations where all subsystems are in a phase of growth.

So as a conclusion, we postulate a direct correlation between technological complexity and the probability of the requirement for a permanent combination of explorative and exploitative learning. Furthermore, and again dependent on the level of complexity, this requirement expands gradually down the value chain. In a nutshell, we propose the following hypothesis: with the increasing technological complexity of a product and its subsystems, the enforcement of permanent ambidexterity rises and expands from the OEM down the value chain. As elucidated in the next subsection, we find evidence for this in the aerospace and automotive industries.

6. Discussion of Results: What Automotive Managers Can Learn from the Aerospace Industry

As presented above, industries can be clustered depending on their product's complexity. We present evidence from two industries. The aerospace, or rather, the aircraft industry is a prototypical example of a complex product industry [38]. The automotive industry produces a product that is indeed complex, where in addition to connected-car topics and autonomous driving, the powertrain can be seen as a dominant subsystem.

We refer here to the aircraft industry as the main object of observation. Space and satellite technology projects will nevertheless be inspected, as well, since the two branches of the aerospace industry are interconnected at the company level, as well as at the thematic level, and spillovers are commonplace. Today's aircraft industry can be regarded as being positioned in a growth/mature phase within the industry life cycle, where a dominant product design was established decades earlier, and OEMs face the challenge of ramping up their production and shaping their production system to be more efficient. These challenges, combined with the importance for the competitive process of learning curves, economies of scale, barriers to entry, and financial resources, have brought large firms with intense power to the forefront of the innovation process [93–95]. Concerning aircraft design, with the exception of the Concorde, there have been no radical changes, and no new trajectory concept is in sight. Engineers may thus be expected to further develop existing designs, improving the technology and the production system by, e.g., using new materials and intelligent solutions in aerodynamics, a rise in electrification in every part or segment of the aircraft, and lean production methods. In general, aircraft complexity and high market and financial uncertainty lead to the need for system integrators (Airbus or Boeing) to maintain an established aircraft design, allowing components to be used in more than one aircraft model, as well as to further differentiate the value chain and establish risk- and revenue-sharing partnerships. Therefore, the aerospace industry can be characterized as a technology-intensive sector, with a high R&D intensity, technological complexity, high and increasing development costs, long product life cycles, long break-even periods and small markets, problematic cash flow situations, high market-entry barriers, and a high governmental influence in the form of ownership, regulation and as customer [95–97].

While the aerospace industry is a prime example for an industry with complex products [34], the automotive industry developed—after the very early phase with open technological design—in an environment in which the internal combustion engine was the dominant design. With the call for more sustainability on the governmental and demand side, the automotive industry faces the challenge of radical innovation in its dominant subsystem. Transformation of the knowledge base in the form of deepening the existing knowledge base and widening the knowledge base on a technological scale is a classic example of cyclical ambidexterity. However, electrification of the powertrain is not the only key challenge. Its technological convergence with connected-car and autonomous-driving technology is transforming the automobile industry towards a complex product system.

We analyzed the development of knowledge dynamics in the aircraft and automotive industries by screening patent disclosures with respect to the conventional powertrain and electric powertrain, whether battery or fuel-cell electric, for the automotive industry, and the development of the overall aircraft system for the aircraft industry. The patent applications of Daimler and Airbus served as reference points within the timeframe of 1991 to 2011 Figure 3.

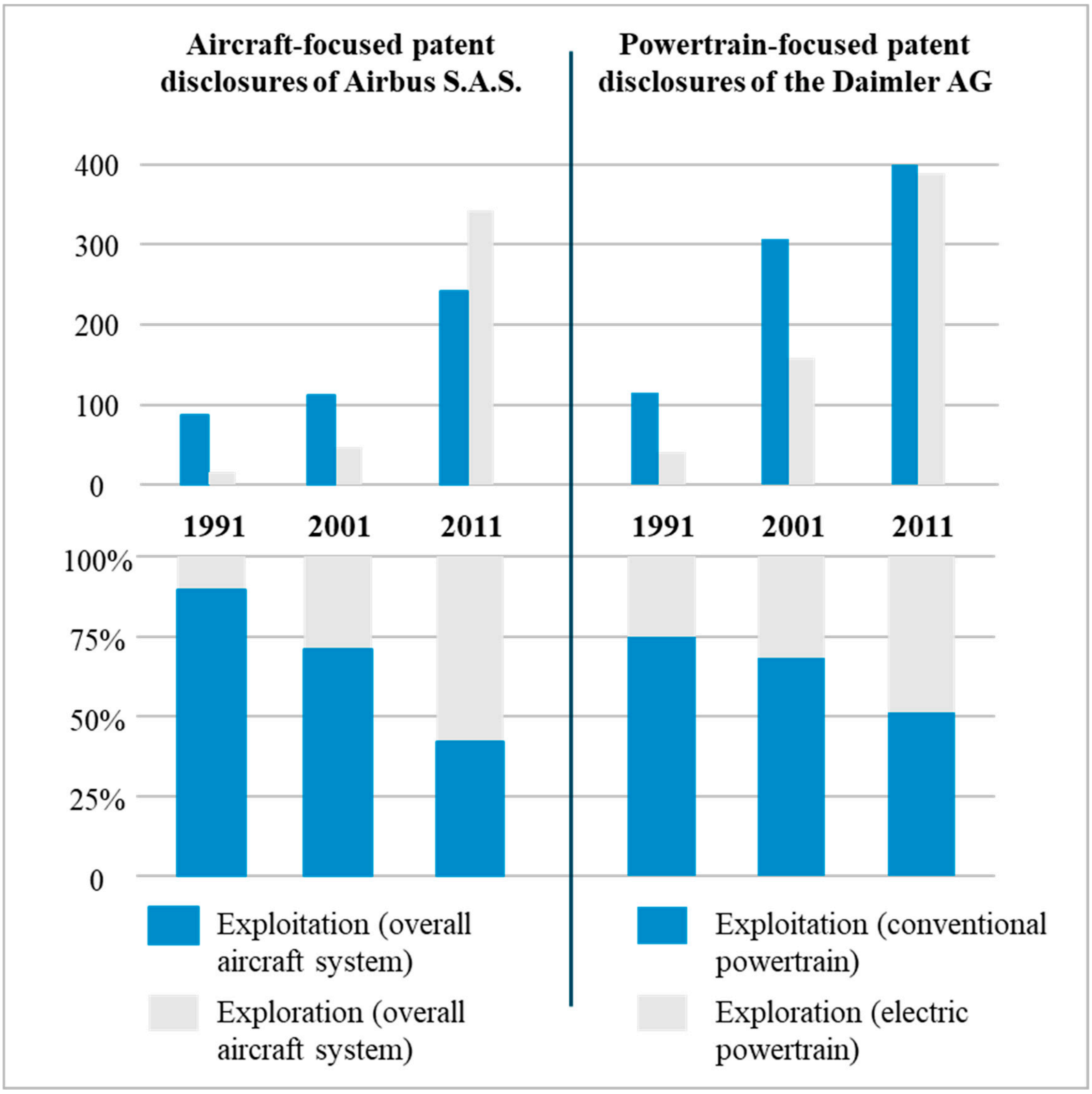

Figure 3. Exploitative and explorative dynamics within Daimler and Airbus.

The increase in both types of learning—for the aircraft industry doubling exploitation-related patents and even increasing explorative patents sevenfold—is immense. Exploration increased proportionally from 30% in 2001 to 60% in 2011 for patents of the overall aircraft system. This is quite surprising, as aircraft seem to have been in an exploitative stage of dominant design since the 1960s [98]. The interlocking of Airbus as orchestrator of the innovation and production network leads to a situation where Airbus is cross-linked in the development of every one of the subsystems, i.e., it is permanently ambidextrous. On the other hand, many cross-disciplinary interrelations with space technology in the form of new materials and explorative behavior is key for Airbus [3]. In addition to the fact that manufacturers are working on new designs to counteract the demands for more speed, sustainability and safety, the huge demand for new aircraft, and thus the need for better manufacturing processes, is certainly also a key reason [4]. The constantly increasing intensity of competition and accelerated innovation cycles also lead to increased patent applications in the automotive industry. For Daimler, we observe an equivalent picture of rapid increase in patents for fuel-cell and battery electric driving, as patent disclosures related to this explorative fields were equal to those related to the conventional powertrain in 2011. Due to the fact that conventional powertrain technology has been exploited over the last 100 years, automobile manufacturers are now being forced to develop alternative drive train technology in an explorative manner. In consequence, they need to be cyclically ambidextrous with respect to their dominant subsystem, which will be gradually transformed over a temporary phase of hybridization [2]. This fundamentally uncertain reconfiguration process is well complemented by and interconnected with the development of connected mobility and autonomous driving, especially the latter of which has the potential to be disruptive for the established business model of car manufacturers. The combination of these dynamics increases the complexity to a degree, so that automobiles must hereafter be seen as complex products. Accordingly, automotive managers must acquire and reinforce skills and organizational capabilities for permanent ambidexterity, just as aerospace managers had to in the past. On the one hand, this includes open innovation networking with startups and SMEs for external explorative learning, while on the other hand realizing an even greater efficiency in exploitation to generate the financial scope to do both. The organizational anchorage of this ambidexterity is the main key for successful long-term development under the technological requirements of the automotive future. A superior strategy for forming predominantly explorative skills while simultaneously reinforcing the necessary exploitative capabilities is the ambidextrous coordination of heterogeneous innovation streams within one organization [2]. While hierarchy-based orders are a superior coordination mechanism for exploiting mature technologies, exploration can be improved by trust-based technological collaboration in innovation networks. This is also supported by Witt, who emphasizes that even if efficiency can be stimulated by the introduction of monitoring and governance devices, the firm is likely to suffer from the fact that this leads to the discouragement of individual initiative and innovativeness [13]. This trust-based cooperation in a truly connected innovation process empowers organizations to develop dynamic capabilities on a higher level, which are a key prerequisite for long-term entrepreneurial success. As we have seen for both the aircraft and automotive industries, the further increase of product complexity and technological convergence, as well as the shortening of product life cycles and the intensified competition between established and new players, more than ever requires organizational ambidexterity comprising path-led exploitation as the foundation of short-term competitiveness and ground-breaking exploration as the foundation of long-term competitiveness. In particular, the heterogeneous coordination of both innovation streams leads to competitive advantage and empowers organizations to combine experimental and cooperative exploration with hierarchy-led exploitation, which facilitates increasing the necessary financial resources in the competition on price. The willingness to moderate one's own independence by consciously incorporating oneself into an innovation network is a prerequisite to enforcing this goal. Therefore, it is necessary to consider a long-term orientation of technological cooperation in order to enable the formation of a basis of trust and relational capital.

To gain deeper insight into the interdependence of the supply chain level and ambidextrous learning, we compared the two value chains of both industries and investigated their size and type of learning (see Figure 4).

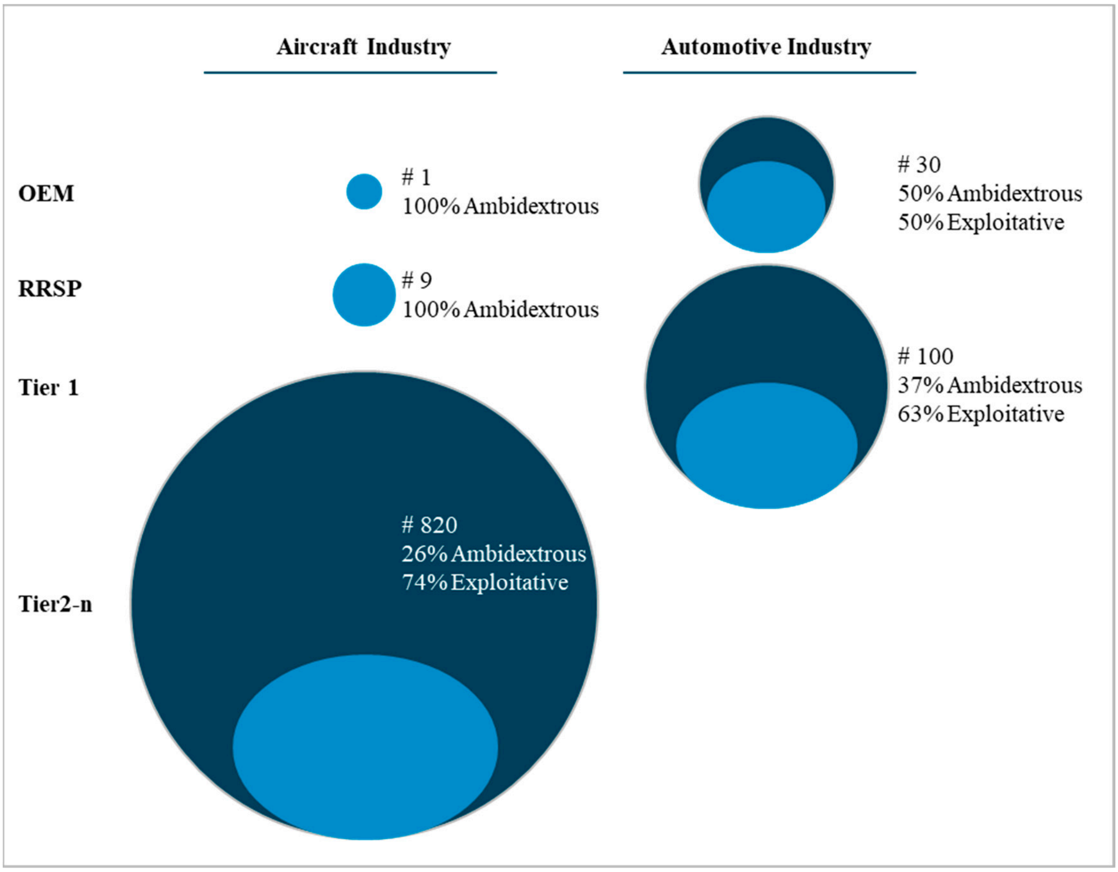

Figure 4. Ambidexterity per supply chain level in the automotive and aerospace industries.

The aircraft industry in Europe shows a broad base, mostly composed of SMEs and specialized companies paired with only one OEM and about 9 RRSPs. Risk- and revenue-sharing partners are companies that develop and produce large subsystems of the overall aircraft and are thereby comparable with automotive Tier-1 suppliers. While the OEM and all RRSPs are permanently ambidextrous, the OEMs of the automotive industry only show an ambidexterity rate of 50%, which means that they are innovating in conventional and electrical powertrain technology. The rate of ambidexterity of automotive Tier-1 suppliers is 37%. Under the recent dynamics of e-mobility, this seems to be a phenomenon of routine-based and path-oriented behavior to maximize profits, but also represents a shortfall of preparation for the upcoming technological cycle. This behavior is obviously a strategic threat to the existence of the concerned companies. With regard to this strategically questionable behavior, it is probable that some companies are not able to adequately invest in exploration due to their inefficient exploitation routines, which will, without much doubt, result in the loss of their market position after the constitution of a new technological paradigm. Individual fields of action can be derived on the basis of the value-added stage, internal efficiency, dynamics of technology and industrial structure, as well as integration in explorative networks.

Car manufacturers, as overall system integrators, form the peak of the automotive value chain and are, without exception, affected by the change of the technological paradigm in powertrain technology. Accordingly, their explorative engagement rate should be 100 percent, if they aspire to keep their market position. Those who fail at ambidextrous technological learning will most likely be squeezed out of the market by the emerging technological and resulting structural dynamics. This will even be accelerated by the market entry of multiple new competitors, such as Tesla or BYD, who conscientiously follow an explorative focus to create and scale the new technological paradigm. To cope with this challenge, established car manufacturers have complemented their path-led, routine-based and hierarchy-driven exploitation business with trust-based cooperation for exploration in heterogeneous innovation networks. It is a paradox, that exactly the kind of behavior which made them successful oligopolists provides them an inferior basis for potential-oriented modes of explorative learning and networking. For the suppliers, the situation has to be analyzed in a more differentiated way, because not all of the 100 biggest suppliers, globally, are engaged in powertrain business, but all are definitely exploitatively engaged within their core business. Due to the fact that the conventional powertrain is the dominating subsystem within the automobile, a majority of the suppliers are also exploiting this field. Many, but not all, of these companies are additionally exploring electrical powertrain technology, i.e., they are acting ambidextrously. For some of them, this is even an imperative, because their previous products will be obsolete, and thus their knowledge base will be without any value once the paradigm shift is finalized. Furthermore, several suppliers who have not been active within the conventional powertrain are seizing the chance to enter this field through the strategic window of opportunity during the change of the technological paradigm. This ambidextrous strategy is often based on existing knowledge base in relevant fields, especially electrical or chemical engineering, that was originally built up in different domains. Furthermore, similar to car manufacturers, there are probably suppliers who cannot afford explorative activities due to inefficient exploitation in their core business. In summary, the explorative engagement of the supplier group is too low by far, such that market squeeze-outs by the technological paradigm shift are very likely. Specifically, because of the expected gradual transformation between the conventional and electrical paradigms, with an intermediate hybrid-phase, they are losing a unique chance by failing to learn ambidextrously.

7. Conclusions

In a nutshell, organizational learning is the central parameter of economic evolution and success. As technology develops over trajectory shifts, companies are at last cyclically forced to learn ambidextrously, or are squeezed out of the market. On the one hand, this includes open innovation networking with startups and SMEs for external explorative learning, while on the other hand, realizing an even greater efficiency of exploitation to generate the financial scope to do both. The organizational anchorage of this ambidexterity is the main key for successful long-term development under the technological requirements of the automotive future. Analyzing the aerospace industry, which is accepted to be emblematic of a complex product industry, we showed that all OEM and RRSPs are already working ambidextrously, and even one in four suppliers on lower levels of the supply chain are doing so. Since the recent paradigm shift in the dominant subsystem of the automotive powertrain from combustion to electrical engines—in convergence with connected and autonomous driving technology—the automobile is becoming a complex product; at last, car manufacturers have to implement the meta-skill of permanent ambidexterity. Currently, this is only being achieved by every second OEM and every third supplier. Companies that fail in doing so will be unable to act as successful integrators of the emerging complex product system. For the tier-1 level, it is becoming apparent that system suppliers, i.e., RRSPs, will be responsible for cyclical independent but interconnected subsystems, which finally demands cyclical ambidexterity from them. As soon as one of these subsystems takes shape as complex in and of itself, the requirement of permanent ambidexterity expands down the value chain, as we have already been able to observe in the aircraft industry over the past decades.

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