



Desmond Hickie
University of Chester
✉
deshickie@gmail.com

Diversities of Innovation in Advanced Manufacturing – the aerospace and automotive industries

*Diversidades de Innovación en Manufactura
Avanzada – Las Industrias Aeroespacial y de
Automoción*

I. INTRODUCTION

The aerospace and automotive industries have each played a major role in the development of modern societies and economies, providing highly skilled employment and allowing consumers unparalleled mobility. In both industries technological advance is vital to product differentiation, and hence to firm competitiveness. Both are in a state of rapid technological change. However, innovation is not simply a technological matter for them. In order to identify, evaluate and pursue technological opportunities individual firms require a range of managerial, organizational and commercial capabilities.

At first glance, the innovative opportunities for automotive and aerospace industries can appear almost limitless in their diversity. However, in practice, innovation involves choices and risks. The wrong choice can threaten the competitiveness, even the very existence, of a firm. In making these, often difficult, choices a firm needs to consider not only its own internal resources. It must also consider the resources and constraints of its external environment – customers, suppliers, labour markets, government regulators, etc.

The aerospace and automotive industries have much in common. Both are assembly industries taking tens of thousands – even millions - of parts to make vehicles. Their research and



EXECUTIVE SUMMARY

This article explores the diverse opportunities for innovation in two advanced manufacturing industries, which make widespread use of high technologies, and for which there seem to be almost limitless innovative opportunities. It analyses the forces that impact upon the industries – in particular, the variety of technologies they employ, globalization, market structures, supply chain capabilities and regional ecosystems. It is argued that these forces both make innovation essential for firm competitiveness and entail risks that require high levels of managerial skill, technological capability, financial resources and entrepreneurial acumen. Finally, the article explores the likely future impact of digitisation on innovative opportunities in these industries.

RESUMEN DEL ARTÍCULO

Este artículo explora las diversas oportunidades de innovación en dos industrias manufactureras, que hacen un uso generalizado de tecnologías complejas, y para las que parece haber oportunidades innovadoras casi ilimitadas. Analiza las fuerzas que afectan a las industrias, en particular, la variedad de tecnologías empleadas, la globalización, las estructuras de mercado, las capacidades de la cadena de suministro y de los Ecosistemas regionales. La investigación argumenta que mientras estas fuerzas hacen que la innovación sea esencial para competitividad de las empresas de estos sectores, entrañan riesgos que requieren altos niveles de habilidad directiva, capacidad tecnológica, recursos financieros y actitud emprendedora. Finalmente el artículo explora el probable impacto futuro de la digitalización en las oportunidades de innovación en estas industrias.

development are generally closely linked to particular product developments and are hugely costly. Production is immensely capital intensive and based upon globalized and tiered supply chains. Civil aerospace is an effective Boeing-Airbus duopoly. Currently, in automotive some industrial concentration is underway as technologies proliferate and development costs rise.

There are, however, some key points of difference between the two industries. The automotive industry sells to both consumers and producers, whereas aerospace is almost exclusively a producer goods industry, selling to airlines and aircraft leasing companies. Both industries have high levels of political saliency and their technological development is much influenced by government policy (e.g. safety regulation). Finally, while neither industry is based on short-termism, their time horizons are markedly different. New automobiles tend to be designed, built and sold on a seven-year cycle, whereas the design and development alone of a wholly new aircraft can take seven years or more, and it may be in production for decades.

The aerospace and automotive industries have each played a major role in the development of modern societies and economies, providing highly skilled employment and allowing consumers unparalleled mobility

2. THE NEED TO INNOVATE – SUPPLY CHAIN DIVERSITY

Because both industries make vehicles they have core technologies in common: designing and manufacturing vehicle bodies, engines, control systems and interiors. Hence, there are many overlaps in their innovation priorities. Both are deeply involved in the development of new types of engine that use less fuel, or may use new fuel sources (notably electric engines). Both are interested in making vehicles that are both lighter and more aerodynamic, so that they burn less fuel and are less polluting. Sensor technologies offer a key means of improving the reliability and maintenance of both cars and aircraft. Robots are already widely used to enhance the speed and reliability of production processes.

In order to develop innovatory new products, Original Equipment Manufacturers (OEMs) like Airbus or General Motors have to embody multiple technologies in their new vehicles. Each technology brings its own diverse opportunities and choices. For example, an innovatory new automobile like the BMWi8 hybrid

sports car does not simply incorporate an innovatory power train. It incorporates a range of other innovations (e.g. an aluminium chassis and a carbon fibre passenger compartment). Engaging with multiple technologies adds diversity and complexity to the supply chain. Firstly, OEMs do not own the intellectual property, or have sufficient expertise in all the technologies embodied in their vehicles. They rely heavily on suppliers to be at the leading edge of their specialist technologies (e.g. Boeing relies on global aero-engine makers, like Rolls Royce or General Electric). This implies a very strong dependence upon the technological, managerial and financial capabilities of the engine supplier, which impact directly on the competitiveness of a new aircraft. Secondly, many valuable new technologies are within the expertise of companies outside the traditional aerospace or automotive sectors, which are newer entrants into their supply chains. This challenges OEMs by adding technological and organisational diversity and cost pressures. For example, they need to develop the engineering expertise both to understand and use these new technologies in their products and processes (e.g. 3D printing). However, the technological, organizational and commercial pressures are not identical for both sectors. For example, automotive is a mass production industry and so is a leader in process innovations that cut manufacturing costs (e.g. Just-in-Time technology in the 1980s), whereas in aerospace, weight reduction is critical - hence its leadership in the use of composite structures. In aerospace, arguably the biggest long-term challenge is to develop technologies to produce very large composite aero-structures, which could revolutionise airframe design. Whereas, in automotive, reducing cycle times for manufacturing composite body structures is a more pressing challenge, because cars are produced in much greater numbers than aircraft.

Currently, key commercial pressures in the two industries are somewhat different. Some automobile manufacturers face quite severe challenges simply to pay for the R and D upon which their futures depend, because the market is crowded and global demand is sluggish. (Global demand was stable in 2018 at about 86 million vehicles). Thus there are global pressures towards industrial concentration (e.g. General Motors sold its European operations to PSA in 2017) and towards R and D collaborations in product development, which enable innovatory developments that

KEY WORDS

Industry 4.0;
Advanced
Manufacturing; Supply
Chain.

PALABRAS CLAVE

Industria 4.0;
Manufactura
Avanzada; Cadena de
Suministro.

individual automakers would struggle to finance. In contrast, civil aerospace is a duopoly and global demand forecasts for airliners are buoyant. (Boeing is forecasting that 44,000 civil airliners will be sold between 2019 and 2038.) So, whilst the costs of R and D are huge and challenging in aerospace, it is clear that over time a successful airliner will be able to repay its development costs. Commercial success, however, requires a firm to choose the right innovation and pursue it competently –no easy task.

3. DIVERSE, BUT COMPLEX, INNOVATIVE OPPORTUNITIES IN TECHNOLOGIES OLD AND NEW

The development of a new vehicle (a car or airliner) is a vast undertaking. It is likely to involve a diversity of innovations, some incremental and others more fundamental (e.g. electric motors, carbon fibre structures). Such innovations can bring product differentiation and market competitiveness, but also uncertainty, cost and risk. In the automotive sector, currently life is difficult for OEMs launching innovatory new vehicles. Automotive manufacturers are currently faced with the need to undertake major innovations (new types of engine, driverless vehicles) that may take many years to develop. Consumers expect more economical, safer and more environmentally friendly vehicles. Equally, government regulators are setting higher emissions and safety standards. Not to innovate is to lose competitiveness. However, stable demand and a crowded market are not conducive to making huge technological investments, and the precise trajectory of long-term demand is difficult predict (e.g. the adoption rate of electric vehicles).

To offset demand uncertainty and the inherent financial and technological risks, manufacturers are seeking to collaborate with one another (e.g. on common vehicle platforms). This is a sensible strategy, but carries with it increased complexity, as the automotive OEMs have to manage their collaborations and subsume their particular technological ambitions within a common project. These organizational innovations might appear in principle to reduce the diversity of potential innovations, but in practice are likely to create more successful innovations, as collaborating firms undertake projects jointly that they may be incompetent, and lack the resources, to fund individually.



For Boeing and Airbus the decision to develop a new airliner is, if anything, even more complex. The lifecycle of a new automobile is about seven years. A successful aircraft will take longer than this simply to enter service, and may be in production for decades. Hence, the decision to develop a new airliner is a response to airlines' projections of future demand for several decades ahead. In principle, this may seem relatively straight forward, given the projected buoyancy of global demand. But, in reality, it is far from easy. For example, Airbus's decision to build the A 380 superjumbo in the early 1990s was based on accurate long-term predictions of growing passenger traffic in the early 21st century, but misjudged passengers' precise requirements. Experience eventually showed that passengers preferred to fly in the 787 Dreamliner, as it allowed direct long distance flights without the need to change planes at hub airports. However, even Boeing's foresight was insufficient to ensure it the market leadership it might have expected. To offset the huge development costs of the highly innovatory 787, Boeing relied too heavily on its leading suppliers to fund and manage their own R and D. In practice this led both to manufacturing issues and the grounding of the aircraft soon after it entered service (due to fires in its Lithium batteries). Having correctly forecast consumer preferences, Boeing's managerial innovations failed to deliver the aircraft on time and to cost. In summary,



55

“The jet makers spend years and millions developing jet engines for planes that don’t exist, while the plane makers like Boeing and Airbus spend years and millions developing planes that won’t fly without engines that do not exist.”
(Baldwin, 2019, p.93)

If launching technologically advanced vehicles is challenging for established OEMs, it is much more so for new entrants. In automotive, new entrants have followed diverse strategies to develop innovatory models. For example, Tata were able to draw on the vast engineering and industrial experience of the whole Tata Group, in creating the Nano - a cheap, technologically simple small car, designed explicitly to serve a new market sector in India. Yet, even with market familiarity, the Nano has not been the success, because of production and perceived quality problems. Tesla adopted a wholly different strategy, developing



a technologically very advanced, luxury all electric car, designed to compete initially in the US, and then globally. Its battery and recharging technologies were highly innovatory and remain market leaders. The company's growth has been encouraged by an ever more favourable regulatory environment yet, 15 years after Tesla entered the market, the company is still experiencing higher levels of manufacturing faults than would be acceptable to other luxury car makers, and in 2018 lost \$1 billion. Both Nano and Tesla illustrate that successful innovation involves not only successful product technologies, but also manufacturing technologies capable of delivering a perfect vehicle on time every time. In recent decades Chinese automotive companies (such as Dangfeng) have followed a more conservative and collaborative market entry strategy, either building partnerships with well-established manufacturers (e.g. with Renault and Nissan), or through acquisitions (such as Shanghai Automotive's takeover of MG/Rover). This strategy allows the novice manufacturer to draw on the design and process skills established partners. Their experience indicates that for newcomers, even with an enhanced knowledge base, the successful design of whole cars *ab initio* requires deep pockets, and patience, because it is unlikely that early vehicles will be globally competitive.

In aerospace the task of designing and building a whole aircraft from the beginning is even more challenging. The most successful example is Embraer of Brazil, which over a period of decades achieved huge success with smaller, regional jets. COMAC of China is a more recent entrant and is illustrative of the inherent difficulties involved. Its new airliner, the C919 (a competitor to Boeing 737 and the Airbus A320) has now flown successfully, but its development is years behind schedule – and no doubt over budget. Without patience and deep pockets entry or re-entry into the aerospace market as an OEM is not feasible, as the sale of Bombardier's airliner interests to Airbus in 2018 illustrates. Finally, it is important to note that new entrants must rely on the global supply chain of experienced aerospace companies for many of their key technologies, as COMAC does (e.g. with Honeywell, CFM and General Electric).

For supplier companies in the automotive and aerospace there are diverse innovatory opportunities, depending on their experience, their technological and managerial capabilities, and where they

wish to locate themselves within the supply chain. For established, often global, Design and Build suppliers in the upper tiers of the supply chain, the desire of OEMs to co-innovate (sharing costs and risks) and to rely on fewer suppliers potentially strengthens their position in the supply chain. They are enabled to build a technological knowledge and skills base that is discrete from that of the OEMs they supply, adding to the diversity of potential innovations. This in turn increases the interdependencies within the supply chain, and so strengthens their competitive position. However, this carries with it a danger for OEMs, because in the long run they can lose understanding and control of technologies upon which their competitiveness is critically dependent. Boeing's decision to make the 777X wing in-house rather than in Japan illustrates an awareness of this issue.

Lower down the supply chains at Tiers 3 and 4, firms are often smaller, can be locked in to older technologies and have less sophisticated management, both in their awareness of impending technological changes and their ability to manage within a global supply chain. For example, some small suppliers of, say, conventional metal fastenings may find it difficult to adjust to a market where their customers move substantially to composites. Similarly, Just-in-Time automotive manufacture can require suppliers to deliver components to the production line with lead times of 45 minutes. This entails a degree of sophisticated logistics management that may be beyond them. K&Z Consulting found, worryingly, that many smaller, but well established, players in aerospace were ill equipped to meet the managerial challenges of the 21st century supply chain – about one third of German suppliers in 2013. Such suppliers are likely to be displaced by more innovative competitors offering new technologies, more efficient manufacturing and/or better logistics.

For new suppliers who might enter these industries there are opportunities to innovate and even displace less efficient suppliers. Build-to-Print suppliers manufacture components to a design provided by a customer further up the supply chain. This is simplest, least risky way to enter the supply chain. Even so, to set up as a new Build-to-Print supplier company in a well-established supply chain is not easy. The aspiring company must have a competent labour force (e.g. blue collar manufacturing employees working to industry standards, experienced supply chain



managers capable of working internationally, and engineers able to understand the technical specifications and to devise process innovations) (Baker, 2019). OEMs will expect even small suppliers to understand the culture and practices of the industry and to make some of their own process innovations. These barriers can be overcome with patience and investment (e.g. Strata the Abu Dhabi-based manufacturer of composite aerospace parts). Such suppliers can enhance the geographical diversity of the supply chain, but are unlikely to be major innovators.

Entry into these sophisticated manufacturing supply chains at more advanced levels – designing as well as building major components, or manufacturing whole vehicles – is a much more challenging proposition. Designing components requires not only the mastery of the firm's own particular technology, but a capacity to understand the technology of the vehicle as a whole. Hence, a firm with Design and Build ambitions faces more demanding financial, technological and managerial challenges (e.g. employing a design team over a period of perhaps 10 years whilst it develops its technological and team working capabilities). Such barriers can be overcome (e.g. by Aernnova, the Basque aerospace manufacturer of composite structures). Rapid technological advance in both sectors creates diverse innovative opportunities, but these involve risks and uncertainties even for firms with decades of experience. For new entrants, the risks and uncertainties are almost inevitably greater.

For firms participating in these industries, there are also two geographical considerations that can impact upon their success – one is globalization and the other is their regional ecosystem. The geography of the automotive and aerospace industries has shifted over the past decades as OEMs and their Tier 1 and 2 suppliers globalized their supply chains. They relocated activities abroad, in particular to developing economies where costs are lower and where there is a ready supply of skilled and well-educated labour – especially where such a relocation brings enhanced market access with it (e.g. Volkswagen has plants in the Czech Republic, Hungary, India, Brazil China and Mexico – among many others; and Rolls Royce has its own major engine plant in Singapore). This globalization certainly enhances the diversity of manufacturing activity, but it does not necessarily greatly enhance the diversity of innovation. A small Build-to-Print supplier of automotive parts



in Eastern Europe may make process innovations, but these are likely to be minor and specific to its local context, so adding little to the innovatory profile of the global industry. However, as K&Z found in aerospace, there are many innovatory suppliers in developing economies capable of competing effectively in the global supply chain (e.g. Indian software companies supplying the aerospace - and the automotive - industries). Not only do they add to the geographical diversity of the supply chains, but they bring with them new products, processes and ways of working.

Growing globalization and diversity does not mean that successful automotive and aerospace suppliers can be set up anywhere (Hickie and Hilpert, 2019). The most successful regions in the aerospace and automotive industries are characterised by a rich and diverse ecosystem of public and private institutions that support their competitiveness (e.g. Munich, Stuttgart, Toulouse, Seattle). Such institutional networks facilitate the development of new suppliers. For example, the existence of a local labour force with the necessary skills and values to work efficiently in supplier companies implies the existence of an education system capable of educating potential employees to high school, technical college and probably university levels –especially in STEM subjects. Indeed, aerospace and automotive companies often work closely with the educational institutions where their plants are located to ensure the supply of skilled labour (e.g. Washington State runs technical training institutions to train and accredit skilled aerospace workers). National and regional governments also help fund research activities in universities and research institutes, which help to drive industrial innovation. In so doing, they develop research institutions which are magnets for firms' development activities. Hence, M-Byte the Chinese electric car-maker builds cars in Nanjing, but its development activities are conducted at Munich and Santa Clara (California). A favourable regulatory environment can also be critical in allowing the development of new technologies. For example, several companies have been attracted to Arizona by a liberal regulatory environment to test their driverless cars.

Similarly, some components and services provided by the private sector are better supplied from nearby than from a distant supplier in another country. For example, for a new Build-to-Print Supplier it is beneficial to have a local engineering company that



has the expertise to conduct non-routine maintenance for its manufacturing equipment and holds a ready supply of spare parts. New entrants in regions still establishing an automotive or aerospace industry are unlikely to benefit from a sophisticated regional ecosystem. To create one a sector and its infant companies need a formal organisation to brand and market their region, and attract new suppliers. There is then the potential for a snowball effect, building a stronger, deeper regional supply chain. For example, the relatively new aerospace industry in the Basque Country set up HEGAN, to represent the industry regionally and provide specialist facilities that can be shared by member companies. Hence, although aerospace and automotive firms participate in global supply chains, they rely on regional ecosystems, which reciprocally can enhance the innovatory diversity of the supply chain as a whole.

4. DIGITALIZATION/INDUSTRY 4.0 AND A NEW INDUSTRIAL REVOLUTION

To understand the future of innovation in automotive and aerospace, one must explore the impact of rapid developments in a suite of generic, ICT-based technologies.

“Digital technologies had been laughably bad at a lot of these things for a long time – then they suddenly got very good.”
(Brynjofsson and McAfee, 2014, p.5)

These changes go under a variety of names – digitalization, Industry 4.0, Advanced Manufacturing, etc. and they include a group of computer-based technologies, such as Artificial Intelligence, Virtual Reality (VR), Augmented Reality, and Robotics. These in turn often require integration with other advancing technologies, such as Sensors, Additive Manufacturing and New Materials. Furthermore, these advances must also be integrated with specialist technologies developed within the automotive and aerospace industries (e.g. Just-in- Time logistics; fly-by-wire controls). The automotive and aerospace industries make widespread use of these technologies (e.g. VR in design, robots in manufacturing, and in radically new products, like driverless vehicles).



The integrative character of these industries creates diverse innovative opportunities engaging both established OEMs and suppliers, and new entrants with niche expertise in these new technologies. Industry 4.0 technologies are already having an impact across these industries' value chains, from design concepts to the end user experience. The new technologies are bringing forward innovations, that integrate the design process and cut costs (e.g. VR allows engine and component designers to 'see' inside a new engine to optimize its functioning). Once vehicles are in production the capacity to transfer huge volumes of data between OEMs and suppliers creates the potential more closely to integrate manufacturing processes between OEMs and suppliers. For automobile manufacturers, supply chain integration already allows the building of cars to order. In future, as the Internet of Things becomes a reality, integration will become even closer as machines in different locations share data in real time without human intervention.

Automobile customers and airlines already expect to receive vehicles built to their exact specifications. VR has the potential to enhance their experience further. It will enable car buyers to 'drive' the exact vehicle they intend to buy. Airlines can already 'walk' through mock-ups of different airliner interiors to precisely specify their interior layouts. Similarly, sensor technologies allied with instantaneous data transmission have the capacity radically to change the relationship between manufacturers and customers. Currently in aerospace servitisation is cutting the costs of owning an airliner (e.g. Rolls Royce can monitor the detailed performance of its engines in service in real time). This profoundly changes the manufacturer's value chain. For example, in the Maintenance, Repair and Overhaul subsector of aerospace, innovations in Additive Manufacturing has the potential to allow MRO organisations to manufacture spare parts on site only when they are needed.

Given that there are wide ranging innovative opportunities in these two industries, what uncertainties and constraints should firms consider in choosing when and where to invest? Broadly, these fall into four categories -

Firstly, the speed and scale of the technological changes associated with Industry 4.0 are remarkable. For example, thirty years ago Artificial Intelligence was fundamentally an academic



discipline, now high performance computing and the capacity to manage Big Data have transformed its usefulness (e.g. creating a 'digital twin' of a vehicle, which can then feed back into the digital design process, optimizing the design before constructing a prototype). Suppliers unable to manage the necessary large volumes of data in real time are likely to be displaced, except perhaps at the bottom of the supply chain.

Secondly, Industry 4.0-related innovations frequently involve several different technologies so adding complexity, because there are inevitable leads and lags in technological development (Scherrer, 2019). A well-known robotics case is General Motors' Hamtramck plant, built to be the most automated automotive plant in the world in 1985, but a source of endless teething problems, essentially because the robots could not be adequately controlled. More recently, battery technology has been a brake on development for both planes and cars. Using composite materials long cycle times are a particular constraint for volume car-makers, while the limited size of composite aero-structure components is a constraint on radical airliner design improvements.

Thirdly, public attitudes towards new technologies can create uncertainty. Public resistance can come both from consumers (e.g. who are unwilling to pay a market price for a product), or from citizens (who object to its social consequences). These issues are especially troubling in automotive, given sluggish demand and public reluctance concerning some new technologies. For example, Renault and Nissan are developing electric engine technology jointly to cut their individual R and D costs. However, although demand for electric vehicles is growing, it remains low (1.26 million sold globally in 2018). Many consumers are unconvinced by the higher price and shorter range of electric vehicles, and the lack of a widely accessible charging infrastructure. Similarly, whilst the public seems to accept the increasing use of driver aids (e.g. to prevent accidents), they may not be prepared to purchase or use driverless cars (e.g. as taxis).

Public concerns about these new technologies is mediated through public policies that may help or hinder their development. For example, governments have encouraged the development of electric propulsion systems for cars with support for R and D, subsidies for consumers (e.g. in Norway and China), subsidising the development of an infrastructure of charging points (e.g.



Norway), and allowing preferential access for electric vehicles into cities. However, in the case of autonomous vehicles (e.g. drones, autonomous air taxis, autonomous cars) there are significant public concerns about their impacts and usefulness, and high regulatory standards act as a brake on its development. For example, Uber tested its experimental autonomous car in the relatively relaxed regulatory environment of Arizona. However, the death of a pedestrian killed during the trial is likely result in stricter regulation internationally.

Fourthly, even with apparently promising digital technologies, individual firms must make critical investment decisions and evaluate their own capabilities and resources and those of their ecosystems and supply chains. To innovate firms need not only technological knowledge and skills to master 4.0 technologies, but also a blend of managerial and technological skills to assess its potential economic costs and benefits. A strong and supportive ecosystem, especially located close at hand, can provide materials, components and services the firm does not have in-house. Even when a firm has access to the necessary resources, it must make a strategic judgement about how the innovation will enhance its competitiveness and capture greater value in the supply chain (e.g. Rolls Royce's move into servitisation). This can be a difficult decision for some suppliers lower down the supply chain, whose products may be commoditized, easily obtainable globally, and whose prices are often 'soft'.

Adding to this uncertainty, digital technologies have added potentially disruptive geographical unpredictability to investment decisions. Globalization has often meant the offshoring of activities to plants or suppliers in lower wage economies (e.g. automotive plants in Eastern Europe). Usually, this has been predominantly in less technologically complex manufacturing activities (e.g. Build-to-Print). Advances in digital technologies: which allow data to be transmitted, analysed and used in real time (e.g. Big Data, improved connectivity); and, which allow direct human interactions in real time (e.g. VR, Augmented Reality), create the potential for offshoring to grow even further. For example, the Internet of Things would allow robots at European or US car plants to communicate directly with robots at a supplier's plants in South Africa and Indonesia to coordinate production directly without human intervention. Similarly, an aerospace MRO facility in Singapore



could use 3D printed components using data transmitted direct from a manufacturer in Europe.

Such innovations could mean more offshoring, geographically diversifying supply chains to developing economies. However, on closer inspection this seems too simplistic an analysis. Advances in robotics require less of the semi- and low-skilled labour, which gave developing economies much of their competitive advantage. This has the potential to alter the economics of the supply chain. If labour costs become relatively less significant, then re-shoring to newly automated plants in Western Europe or North America becomes a more attractive proposition (Bramanti, 2019). If components can be manufactured nearby by robots, it makes little sense to manufacture them thousands of miles away using other robots. Furthermore, in a knowledge-based economy, competitive advantage lies primarily in people's heads, in teams and organisations. These are found more frequently in well-established industrial regions with sophisticated innovative ecosystems (e.g. Toulouse, Stuttgart).

"Increasingly, value is created by labor working with knowledge – either knowledge clusters controlled by firms..., or knowledge stuck into people's heads in the form of education and experience."
(Baldwin, 2019, p.70)

Regions relying on cheap, less knowledgeable labour, then become vulnerable to advances in digitalization in more developed ecosystems.

5. CONCLUSIONS

Technological innovation is critical to competitiveness in aerospace and automotive, and so is pervasive throughout their supply chains. The potential opportunities for such innovations seem almost endless in their scope, scale and diversity – from the transformative (e.g. driverless vehicles) to the incremental (e.g. minor process improvements). These innovations may take place within well-established firms and technologies, or they can incorporate new firms and technologies into an established supply chain, and so diversify both. They may affect products (e.g. the BMWi8), design and manufacturing processes (e.g. VR, robotics), or both (e.g. 3D printing).



The very existence of this great diversity of innovatory opportunities creates pressure to innovate, as do government regulations and subsidies. So, the need for firms to innovate or die may appear self-evident! What is less clear is what, how and where to innovate. Diverse technologies develop at different rates and with different degrees of practical applicability, creating risk and uncertainty. A poor technological investment can lead up an expensive 'blind alley'. Even experienced entrepreneurs can misread innovatory opportunities in such circumstances (e.g. James Dyson's withdrawal from electric vehicle market in October 2019). Hence, commercially successful technological innovation is much more than a straightforwardly technological matter. It challenges: the managerial skills of companies; their financial resources and their entrepreneurial acumen.

REFERENCES

- Baker, P (2019) "Skilled Blue Collar Labor and Innovation in Manufacturing" En *Diversities in Innovation*, Taylor and Francis, London.
- Baldwin, R (2016) *The Great Convergence: Technology and the New Globalization*, Harvard University Press, Cambridge, MA.
- Baldwin, R (2019) *The Globotics Upheaval. Globalisation, Robotics, and the Future of Work*. Oxford University Press, Oxford.
- Boeing (2019) *Commercial Market Outlook (2019 – 2038)*.
- Bramanti, A (2019) "New Manufacturing Trends in Developed Regions". En *Diversities in Innovation*, Taylor and Francis, London.
- Brynjolfsson, E and McAfee, A (2014) *The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies* Norton and Company, New York.
- Haskel, J, and Westlake, S (2017) *Capitalism without Capital: The Rise of the Intangible Economy*, Princeton University Press, Princeton, NJ.
- Hickie, D and Hilpert, U (2019) "Traditions, Structures and Cultures" En *Diversities in Innovation*, Taylor and Francis, London.
- Hickie, D (2014) "Competition in International Automotive and Aerospace Technologies" En *The Routledge Handbook of Politics and Technology* Taylor and Francis. London.
- Maisonneuve, F, Santo, M, Menard, H and Schmid, J (2013). *Internationalization and Competitiveness of aerospace suppliers, A Joint Analysis of Germany and France*. h and z Unternehmensberatung AG, Munich and Kea and Partners, Malakoff, France.
- Scherrer, W (2019) "Changing Innovative Opportunities during the Life Cycle of Technologies", En *Diversities in Innovation*, Taylor and Francis, London.
- World Economic Forum (2016) *Workforce Strategy for the Fourth Industrial Revolution*

