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Chapter 2: Driving innovation through transformative trends in automotive research and development

2.1. Introduction

Innovation is continually at the forefront of businesses (Addepto 2024; AppleTech, 2024; Signity Solutions 2024). Increased competition, government regulation, and technological advancement all challenge business models. For the automotive industry these challenges include Connected and Autonomous vehicles, Manufacturing 4.0, Electrification and Personal Mobility. Innovation Management enables companies to react to opportunities to launch new ideas, products and services. With increased levels of growth (in both connected and autonomous markets) it is vital automotive companies prioritise innovation to deliver desirable products that meet customers' expectations, align with current and future trends whilst successfully gaining an edge over other competitors. This study looks at current trends within the automotive and associated technology industry. A series of external factors and their growing importance on the automotive sector are discussed. A study of Innovation Management in terms of new organisational structures across the industry is presented. Finally a case analysis of a leading OEM is detailed.

The automotive manufacturing industry has made major systemic shifts in the last 3 decades, moving away from the traditional manufacturing approach towards a more connected, automatic and modern landscape that is able to meet customer expectations and outside factors through the use of real-time data from leaner machines. There has been a distinct shift in the organisational structure of manufacturing that looks to address a more customised product experience for the consumer using differentiation as markets transform into a buyer's marketplace. This is due to the need to increase effectiveness at expanding the product variety, as well as eliminating waste along the value chain. In-depth investigation into competitors across a number of different fields employing

Manufacturing 4.0 technologies to gain competitive success has been examined. A study on the action plans and their feasibility of developing differentiated unique selling points to combat market entry barriers through increasing investments into R&D has been conducted.

This study makes a number of contributions to the existing literature on auto policy evolution and industry analysis. In terms of contributions to policy evolution studies, a dynamic perspective is provided by addressing policy evolution in the automobile industry which is missing in most studies on Indian automobile industry. Unlike most studies which look at policies in isolation and ex-ante or ex-post innovation observations, this study looks at the co-evolution of policies and firms which is a fresh perspective to understand the mechanisms of change. At the level of the automobile industry, this study examines the specificity or contextuality of policies and their impact on firms. On a related note, factors which account for differences in the capabilities of the industry and their co-evolution with policies adapted to grow the capabilities are examined. Finally, the sources of innovation both at policy-level and firm-level are mapped and compared, which brings out the complexity in understanding sources of innovation and their co-evolution.

Fig 2.1: Transformative technologies

2.1.1. Background and Significance

Innovation in the form of new products, processes or forms of productive organisation brings growth to firms and development to economies. At the level of firms innovation in the form of new products or processes or forms of productive organisation can bring growth in revenues and profit margins. At an economic level, innovation is seen as an important force to develop higher standards of living and per capita incomes through prosperity and wealth creation. Therefore it is important to understand sources of innovation and sources of technological capabilities in nations or firms. In this light, this paper explores sources of innovation and sources of technological capability in the context of competitive forces arising out of policy evolution in the Indian automobile industry. The study setting is the Indian automobile industry which has undergone a process of gradual liberalization of policies since 1991. The Indian automobile industry by end 2009 had emerged as one of the fastest growing industries in India with an average annual growth rate of more than 2000. However, the degree of technological capabilities, measured in terms of control over products and processes is low. Therefore understanding of competitive forces arising out of institutional evolution policy is sought through the nature of constraints set out by automobile policy and key agency factors or players involved in shaping automobile policies. This study, on the other hand, explores sources of innovation and technological capabilities of the firms which are often drawn on by policy analysis in shaping policies. The significance of this study also lies in the analysis of sources of innovation in terms of policies framed out of this evolution. And unlike other studies which focus only on the evolution of policies or the analysis of policy determinants, this study focusses on the co-evolution of policies and auto manufacturers instrumental in shaping the policies.

2.2. Historical Context of Automotive Innovation

Due to the unprecedented rate of automotive industry transformation, emerging trends are redefining the underpinning of vehicle design and engineering, with new instruments to rethink system architectures, platforms, and statistics; new styles and design methods; and the need to endow them with the capability for adaptive prognostics and control (VisionX 2024; The Times, 2025). In the last decade, major automotive manufacturers and suppliers started to realize that evolution in technologies had reached a scale, speed, and complexity that necessitated joint efforts and investments to ensure future competitiveness, including the need to rethink cooperative paradigms for disruptive technologies.

The cooperation between automotive value chain actors to achieve the desired long-term vision of case-specific systems of systems will require contemplating initial visions, current state assessments, pathways, and next steps in research and implementation. The dramatically changing landscape of the automotive industry goes beyond the traditional industry actors with automotive development infrastructures and societies. A recent key competition has grown between incumbent automotive makers and advanced technology companies to control the backbone of the transport sector through mobility service control, onboard automated driving, graphical visualization-maps/driver control interactions, and the design and control of travel safety and privacy systems. Such global developments are driving technology and market scenarios and are guiding all changes in the European automotive industry, leading to the converging automotive R&D revolution.

New companies, markets, and ecosystems push for development of full-stack vehicle-centric solutions to ensure safe, affordable, and efficient personal transport automations, targeting sophisticated vehicles with advanced vehicle control and decision-making capabilities. Existing players have to steadily compete against them while facing the grand challenge for a rapid completion under a diversity of scenarios in transformation. Such competition across multiple vendors, synergies, and collaborations necessitate innovative paradigm shifts at policy, architecture, platform, process, tool, and standard levels. Fresh R&D prioritizing and restructuring are urgent to bring and assure disruptive changes in technology targets, time scale, procedures, methodologies, and devices. Different from prior horizons, expectations, and perceptions all at vehicle oriented R&D levels, transformative trends in automotive design and assessment targeted at case-experience system-oriented innovations and breakthroughs are recently in the spotlight among key global automotive players.

2.2.1. Research design

This study applied causal relationships between distributed innovation embedment and innovative performances to explore the significance of distributed innovation to enterprise development. A conceptual framework, including distributed innovation embedment (knowledge collaborative embedment, distributed cognition embedment, distributed structure embedment, R&D capability, innovative performances of China's automobile industry), was proposed according to literature development. By reviewing records about automobiles in international journals, the research status of innovative performances of China's automobile industry and R&D capability was summarized. Furthermore, questionnaires were designed and optimized according to professional suggestions. Distributed innovation embedment was divided into three totals including knowledge collaborative embedment, distributed cognition embedment, and distributed structure embedment. To investigate subsequent models and hypotheses, an empirical analysis was conducted by 117 effective samples. By testing validity and reliability, this study selected sets of variables that effectively reflect the premise indicators and verify constructs. It provided a reference for the analysis of distributed innovation embedment and innovative performances of China's automobile industry.

Innovative performances of China's automobile industry are affected by distributed innovation embedment, including knowledge collaborative embedment, distributed cognition embedment, and distributed structure embedment. This study furthers understanding of distributed innovation and identifies its significance. The global trend of dispersed, industrialized, and collaborative is accelerating as enterprises have increasingly adopted and relied on networks of innovation providers. Distributed innovation is a kind of open innovation in which innovatively relevant ideas, knowledge, and/or resources are searched outside existing R&D institutions. It has been applied in many industries and fields of firm innovation. Although it plays a vital role in an extensive context, little is known about how it affects the innovative performances of the firm in developing countries. Feedback of system improvement is indispensable, particularly for large-scale, resource-consuming, and complex high-tech products, such as automobiles. With the rapid growth of an automobile industry, more and more automobile manufacturers in China have dispersed R&D functions across main cities, joint ventures, and subsidiaries, and in turn, considerable attention has increasingly been paid to the innovatively collaborative embedment of knowledge.

2.3. Current Trends in Automotive Research

The modern automotive industry faces significant challenges. Car manufacturers must develop vehicles that make the roads safe, reduce accidents, achieve free flowing traffic with few congestions, and reduce pollution by effective fuel use. In addition to the improved safety and comfort of vehicles due to better materials and modern technology, most of the improvements are performed in-car. However, some approaches seem more promising: they rely on the ability of vehicles to communicate between themselves, with infrastructure, with road sensors, etc. Such a way to monitor and even coordinate vehicles is seen as a way to compute intelligent ways of transportation. It would make the road smarter, avoid congestions and accidents while enhancing security and fuel efficiency. When looking at this emerging technology, connected cars are viewed not only as a means for a driver to go from A to B but as a user extension like the smartphone is today. That is, services and applications attached to the car should mimic the success of the plethora of applications of the smartphones. What can and should be done in light of such a significant paradigm shift? What is currently done, and what is still possible to do? What is needed is to define a specific vocabulary and principles for this new domain of innovation. So, it is proposed to classify current innovations on the topic of smart cars according to the use made of them. The first classification is proposed according to three perspectives: a vehicle-centric view, where services are viewed in the framework of the vehicle, a vehicle-network view, where the vehicle is connected to other vehicles and infrastructure, and finally a user-centric view, where the innovations concern the driver's needs. Since there is no tangible definition of what is considered a smart car or more generally, a connected car, it is necessary to get a better understanding of the various terms related to the smart car ecosystem. It is noteworthy that many definitions of smart cars have been published; most of them refer to a combination of new technologies and communication capabilities embedded in vehicles to enhance their role and usage.

Fig 2.2: Automotive Trends

2.3.1. Electrification and Battery Technology

Electrification is one of the key trends affecting the global automotive research and development landscape. However, electrification in the automotive industry is inseparable from battery manufacture and development. Therefore, this section focuses on developments in battery technology in the automotive industry and common approaches regarding research and manufacturing initiatives.

The automotive electrification trend is significantly driven by the expected surge in battery electric vehicles (BEVs) production and usage globally. The rapid growth of the electric vehicles (EV) market over the last decade has greatly impacted battery technology, research, and the supply chain. Stringent environmental regulations set by governments require or encourage greater efficiency and lower emissions, which are considered the main drivers of the forecasted increase in BEV adoption. A unique driving force for electric vehicles is in-person demonstration by politicians and high-profile celebrities. Some original equipment manufacturers (OE), such as Tesla, BYD, and Changan, have already greatly impacted EV product development trends. As automakers expand production capacity to meet the growing demand for lithium-ion batteries in BEVs, increasing battery costs and secure supply of raw materials have been brought to the attention of battery researchers. Nonetheless, academia may still have a major role in continuing intensive basic research on new battery chemistries and renewable materials.

The automotive industry is promoting the electrification of a wider range of vehicles to overcome driving range issues. Highway-capable battery-powered electric buses are explored and developed for short routes, as are lightweight and energy-efficient battery electric aircraft for urban air mobility. The power capacity and energy density of a battery have a linear correlation with the size of an electric vehicle (EV). Therefore, it is reasonable to utilize the present-day technical advantages of lithium manganese oxide-free NCM811 battery architecture for high energy density battery packs. Due to the growing importance of short-haul battery electric vehicle technology in the commercial vehicle market, initiating product development for larger vehicles in comparison to passenger cars is worth promoting. Direct air capture is foreseen to be integrated into fuel- and raw material-producing industrial processes in support of a circular carbon-neutral economy. In addition to the growing interest in battery recycling and reuse, battery material mining requirements may be reassessed in terms of alternative energy density chemical formulations or battery system architectures.

2.4. Impact of Industry 4.0 on Automotive R&D

The automotive sector is one of the most innovative and influential sectors in the world economy, with a total volume of approximately one trillion euros, accounting for around 8% of European GDP. Even though the automotive sector is one of the most R&D-intensive sectors, executives are still doubtfully aware of any major disruptive trends affecting the sector as slow-moving. Yet, new innovative opportunities for services, products, and business models for vehicles and roads – dynamic content or better pre-defined mobile services – are expected to emerge in the medium to long term. Low-emission vehicle propulsion and more cost-efficient propulsion components are perceived as highly significant developments in the automotive sector in the efforts to reduce greenhouse gas emissions worldwide. The pressure for automotive OEMs to introduce new low-emission vehicle propulsion technologies and the supporting infrastructure is thus influenced by government regulations regarding fuel economy and greenhouse gas emissions that lead to legally binding vehicle price increases for CO2-

neutral technologies. For design and manufacturing new profound integration of distributed intelligent computational nodes into novel high-complexity. Because of the extreme reliability and durability requirements, automotive software/hardware and manufacturing often vastly differ from consumer computing devices, although their performance is typically much slower and manufactured in well-established manufacturing processes involving sophisticated material engineering. Designs, devices, models or papers protecting intellectual property rights cannot be fabricated in the standard automobile manufacturing plants until a secret and its protection become well established. The fabrication of automotive components using at least other than standard material systems and often using other than standard fabrication processes is assigned to a component supplier. The consideration of this secret-transfer process is often glossed over. Nevertheless, market competition pressures to reduce costs or time-to-market have led automotive OEMs to outsource the fabrication of software/hardware systems or design to co-design to co-design/verification analysis of high-chip complexity systems on macro, full-custom and standard-cell implementation.

2.4.1. Big Data and Analytics

In the last century, the automotive industry underwent a radical transformation. Cars evolved from handmade luxury items to consumer products. Every aspect of the vehicle's economy of producers, suppliers, retail, aftermarket, and end-users radically changed. The second revolution is about to take place and hopes to be another significant technological breakthrough. Invention and incorporation of unprecedented concepts will transform and practically redefine cars, their production, and operation. Light vehicles have already become mobile communication devices with driving capabilities. However, this trend does not merely concern cars. The need to rethink concepts shouldn’t spare the whole automotive ecosystem, including OEMs, suppliers, manufacturing, and distribution. New concepts will indubitably bring outstanding opportunities for improvement and innovation, but at the same time, they may compromise and/or turn threatening everything that has built up in the past.

The Internet is allowing a shift from mechanical systems to connected communities of software and people. Significant changes in both what is manufactured and how it gets sold are coming. Cars are global devices, in average crossing operator boundaries once every three weeks, and now being bought and sold for shipping like stocks. In a hyper-connected world, effective vertical competition is critical. Incorporation of big data techniques and market analytics will be decisive for effective vehicle development and operation, as well as to restore confidence in data-hungry services. Artificial intelligence will be instrumental for automatic assembling, inspection, road safety, driving assistance, and a huge variety of service improvements. Yet, in a world of all-pervasive sensors and ubiquitous data streams, the management of the levels of acceptance of such systems and their ethical consequences is bound to be a tough challenge. Current industry rules and operation norms are bound to be seriously assessed and amended to carry along old players.

2.5. Consumer Preferences and Market Dynamics

The automotive industry is currently undergoing a revolution due to a variety of factors including technological developments, increased environmental awareness, and changing consumer behavior. Some of these transformative trends are similar to those that have impacted other industries. Specifically, there are three key changes that are likely to have a profound impact on the automotive industry in 2030 and beyond: digitization, connectivity, and electrification. These trends affect all segments of the automotive value chain and have wide-ranging implications for automotive players. Thus, this report begins with an overview of various transformations shaping the automotive industry. Whereas traditional automakers face falling margins, multinational tech enterprises with automotive ambitions continue to ramp investment. As players assess the implication of shifting rival strategies, the magnitude of transformation across the traditional auto value chain is compared to similarly disruptive shifts across other industries. Since many of the enablers affecting this transformation are well established, there is a sense that auto makers could advance quickly in responding to these trends.

The second area of focus assesses the shifting dynamics in the passenger vehicle segment. This begins with an overview of developments in consumer preferences and corresponding changes in rival cost structures. The various strategic options presented by these market shifts are outlined, including the ways in which each player's strategy is shaped by their legacy. The report then presents a detailed overview of the various business models in the nascent shared mobility market, with an assessment of which players are best positioned to succeed. Changes in how shared mobility is monetized and the implications for industry players are also discussed, as well as developments in the ride hail segment and major initiatives to share the cost of autonomous vehicle technology.

Automotive R&D is currently complex and dynamic, with a lengthy product launch lead time to market. Pace-of-change challenges in customer markets, technology segments, regulatory shifts, and product segments are a growing concern. From a technical perspective, electrification and ITS-enabled functionality are two significant trends of automotive R&D evolution. Industry R&D strategies are changing to adapt to these trends. A large portion of the fuel reduction R&D budget will be reallocated to EV powertrains, which is a new, unexplored segment. Battery supply needs will lead to the balance of power shifting from car-makers to battery manufacturers. The emergence of model shifts and the electrification of each vehicle in an OEM portfolio cause distinctions in R&D size, cost structure, and strategy. In terms of size, new vehicle technologies need significantly enhanced simulation scalability. Models need to be recoverable from coding to textural format to accelerate implementation speed. Model architecture is moving towards an object-oriented poly-glot modelling approach

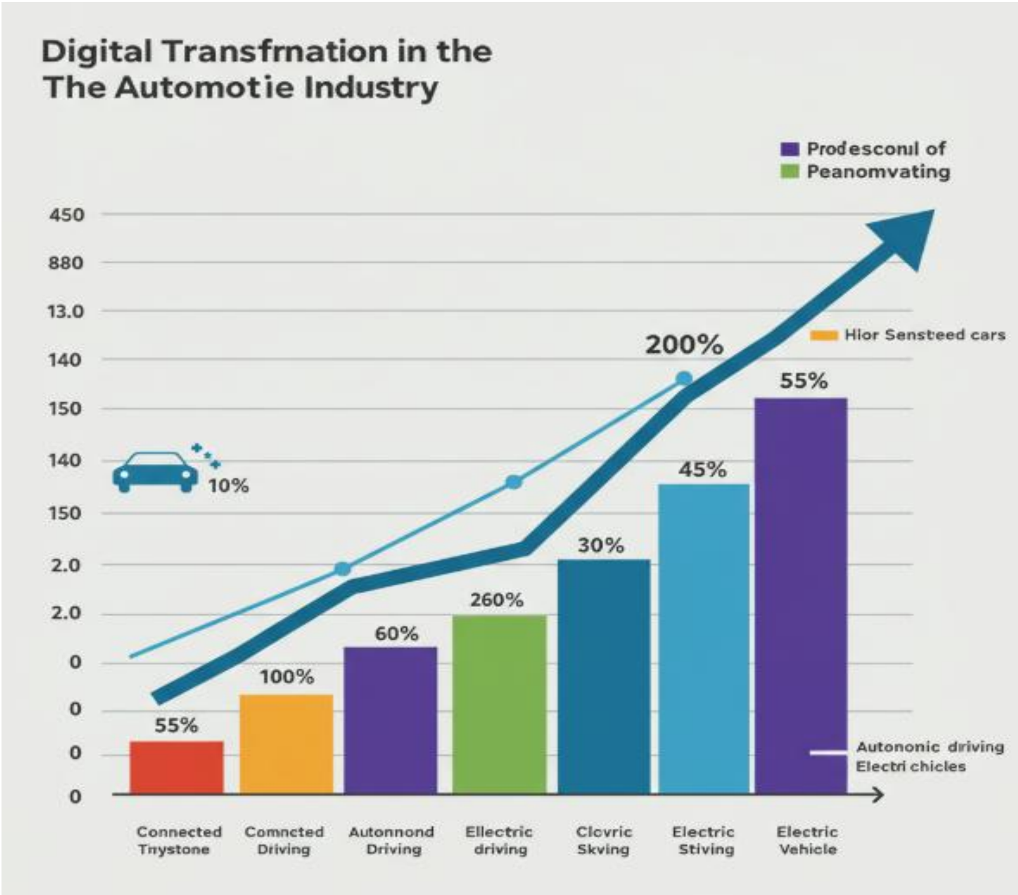

Fig : Digital Transformation in the Automotive Industry

2.5.1. Shifts in Consumer Behavior

From automotive engineers to marketing managers, R&D project engineers to government regulators, the automotive landscape is continually evolving. Emerging business models, evident trends, and the current international political landscape are changing how automobiles solve air quality and climate change challenges. The automotive industry is characterized by several dynamic shifts from both existing markets and emerging segments. Emerging consumer behaviors are explored from the standpoint of the electrified vehicle landscape. Informed interpretations of these shifts are used to highlight potential structural changes across the automotive ecosystem that will enhance competitive advantages in R&D prioritization, technical direction, and product strategy. The automotive industry is experiencing transformations in socio-political, technological, economic, and environmental domains. Policy makers and researchers are increasingly concerned about air quality standards and potential avenues for compliance. As a result, the development of electrified vehicles is an emerging and transformative trend in automotive R&D. Considering near-zero emissions through vehicle electrification, the supply chain and R&D ecosystem will evolve with the paradigm shift in vehicle design and manufacturing.

2.6. Conclusion

Highly automated driving is seen as a promising solution for addressing the need for safer, more sustainable, and more efficient transportation in the future . However, the formalization of specific safety goals and derived safety requirements for highly automated driving functions is an ongoing challenge. Moreover, the reconceptualization of safety-critical, i.e. functionally safe, systems implies that traditional analysis methodologies and verification and validation techniques are no longer sufficient. They need to be adjusted for digital systems with a high degree of adaptable behavior, i.e. systems that are capable of generating behavior that was not anticipated during the development process. Furthermore, tooling for the verification and validation of these systems needs to be developed. The world is undergoing transformation. Globalization and digitalization are affecting the economy, ecology, and society. Fast-moving transformative trends or mega trends are coming together, challenging industries to innovate. Change is happening in technology, markets, regulation, and environments, moving the world toward automated driving, elevated interconnectedness, advanced electrification, and smart mobilities. These transformative trends in the automotive R&D domain are being addressed in the work presented. First, high-level characteristics of change concerning the transformative trends are summarized. Then, the impact of the transformative trends on automotive R&D processes is discussed. Finally, an iterative R&D ecosystem approach is offered as a means for industry and research to collectively respond to the intricate challenges arising from the transformative trends contributing to innovation and economic growth. Keywords: Automotive research; Research process; Trends; Roadmap; Paradigm; Modeling; Method The automotive industry is changing drastically: changing technologies, markets, regulations, stakeholders, and environments; leading to significant new challenges. These challenges are immense and cannot be addressed by actors operating in isolation. New collaborative efforts along an R&D chain are needed, requiring deliberate planning. To this end, automotive R&D processes and their ecosystem context must be understood in detail. In addition, large-scale innovation processes and the positioning of automotive R&D in these processes must be represented qualitatively and quantitatively, and qualified, realized, and sustained long-term and sustainable R&D agenda’s must be generated.

2.6.1. Emerging Technologies

According to a recent statistics published on 1st of January, 2023, 59.3 million cars were registered in the EU, out of more than 300 million in the whole European continent. New connections and communications capabilities have enabled the development of new services and use cases. The data of onboard sensors has become not only a valuable asset for user-oriented applications, but also a source of relevant information to improve the lifecycle of vehicles. Car manufacturers considered as opportunities the RAC, retrieval of data by the connected cars to offer new services, and CAN telescopes, which allow retrieval of status or diagnostics data outside the car. The secondary offer comes from telecoms operators and is based on the answer to the large data collection problem. They are able to build their own platforms and services on an event-based paradigm, and raise information easily accessible to a large audience through data processing and analysis, but the business model of data retrieval is still not convincing enough. Finally, the third category is made of monitoring services and platforms, either specialised in the vehicle lifecycle or more focused on infrastructures.

Improving the functioning of the traffic situation is not enough to improve the mobility of users. The construction of new roads offering better levels of service and the implementation of changes in the public transport service are investments that require assessments on the capacity to attract users. Technologies allowing the monitoring of the number of vehicles circulating on a road include image analysis, detection loops built into the road, and data retrieved from the smartphone GPS signal. Integration with traffic information is generally done with density-based models. In addition, the impact of mobility is not limited to traffic jams: the emissions of pollution and the amount of energy consumed need to be assessed as well. Monitoring speed and kind of vehicles are enough to construct pollutant emissions estimators, while models built on traffic flow use speed and density information.

Evaluating a project consists in observing the effects of the measures implemented. Public statistics related to the travel surveys of a city can lead to understanding the users' behaviour (not all the trips are observed). With a larger scope, geolocation-based technology allows observing the behaviour of a crowd, modelling origin-destination trips, updating them by a minimal amount integrating travel info. A search engine based on social networks collects images and geotags that can be processed to classify images and set up a road map.

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