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U-turn: the rise and demise of the automobile industry

R.J. Orsato [a,*], P. Wells [b]

[a] Insead Business in Society (IBiS), INSEAD, Boulevard de Constance, 77305 Fontainebleau Cedex, France
[b] Centre for Automotive Industry Research & ESRC Centre for Business Relationships, Accountability, Sustainability and Society (BRASS), Cardiff Business School, Colum Drive, Cardiff CF10 3EU, UK

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Abstract

This article introduces the fundamental rational that supports the 'technological regime' of the modern automobile, as well as its potential for inertia, transformation and decline. It presents the main concepts used in automobile design, material selection, and the economic fundamentals that orient today's car assembly and commercialisation. The practices currently adopted by automakers that aim at the rationalisation of systems of production, such as platform consolidation, 'architectures' and modular assembly are briefly discussed. The article inquires into the main reasons for the high pace of consolidation that characterised the automobile assembly and supplier sectors during the 1990s. Subsequently, the discussion about the choice of materials and its impact throughout the life-cycle of cars illustrates the complexities involved in reducing the overall environmental impact of the industry. Finally, by questioning the levels of efficiency of current automobiles and by identifying the core competences of automakers, the final part of the article explains why the automobile industry currently faces one of the most challenging moments of its history.

Keywords: Automobile industry; Technological regime; Industry structure; Environmental issues; Strategies of rivalry; Core competences; Systems of production and consumption

1. Introduction

The economic significance of the automobile industry is remarkable. The commercial value of new vehicles sold is estimated at around €1.1 trillion[1] a year [1]. Car manufacturing is *the* motor of the industrialisation policies and strategies of those countries (particularly Korea, Japan, Germany, USA, Italy, and France) that have a multitude of related economic sectors directly or indirectly dependent on this industrial activity. Automotive technology as a system involves not only the industrial production of cars but also the infrastructure and super-structure associated with their use, maintenance, and partial recycling. Its economic importance is most directly felt in the capacity of the sector to generate wealth through the creation of jobs. In political terms, job creation represents the differential power that the industry has when bargaining concessions for new factories to be established. Since 2000, numerous plant closures have occurred in Japan, North America, and Western Europe: by contrast most plant openings have been elsewhere.

The tremendous economic importance of the industry generates ecological impacts. Significant environmental impacts are associated with all phases of the life-cycle of cars, as well as with related systems, such as road and supply infrastructures. Vehicle manufacturers have increasingly been under pressure to improve their overall environmental performance. Undeniably, progress has been made. Since the early 1990s there is a better utilisation of materials during production cycles through in-process reuse and recycling, and the general

* Corresponding author.
E-mail addresses: renato.orsato@insead.edu (R.J. Orsato), wellspe@cardiff.ac.uk (P. Wells).

[1] All values presented in this article have been converted from United States Dollars ($) and British Pounds (£) to Euro (€), based on the average currency rates for May 2006, according to: http://www.x-rates.com (2006, May 01). Since the numbers intend to give an idea of magnitude, they represent an approximate value of the original currency at the time of the publication of the sources.

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productivity of manufacturing systems has increased substantially [2]. Emissions of particulates and toxic gases during car use have decreased significantly since the 1970s, and schemes for dealing with the non-ferrous content of end-of-life vehicles have been developed in Europe. Fiat Auto, Ford, General Motors (GM), Nissan (now in a cross-shareholding with Renault), Toyota, and Volkswagen, all endorse the principles of the World Business Council for Sustainable Development (WBCSD).[2] Ford and GM also support the CERES principles.[3] In late 1999, Sustainable Asset Management listed Volkswagen as a 'sustainability leader' on the Dow Jones stock exchange. Such practices suggest that ecological issues have grown in importance for vehicle manufacturers.

To assess the extent to which the industry is exploring the potential for reducing the overall impact that cars have on the natural environment, in this opening article of the *Special Issue of the Journal of Cleaner Production on the Automobile Industry & Sustainability*, we present a basic understanding of the nature of the initiatives undertaken by vehicle manufacturers, as well as the overall context in which they have been developed, as well as a basic description of the 'contours' of the complex systems in which the automobile is embedded.

2. The technological regime of the modern automobile

An automobile is not just a physical product of technology. It also has economic, environmental, social, cultural, and political dimensions [3,4]. The dominance of automobiles as a means of transportation refers to a technological system that encompasses more than vehicle manufacturing, use, recycling, and disposal. The automotive technology system also involves infrastructure-related technologies such as the built environment (e.g. road, highways, bridges, and tunnels) and the supply infrastructure, best represented by one of the most influential economic sectors of the 20th century: the petroleum industry. When the entire implications of the automotive technology system are considered, one can think of it in terms of a technological regime. According to Weber et al. [5, p. 16], this regime may be defined as "the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up a totality of a technology".

A basic understanding of the automotive industry requires the identification of the main technological interdependencies between the systems with which automobiles interact. Most economic and environmental challenges faced by the automobile industry have close relationships with the development of other industrial sectors, such as the steel, aluminium, and petroleum industries. Although it has become almost a reflex to acknowledge the economic power of the automotive and related industries, there is still a lack of understanding of the fundamentals of such dominance, or perhaps acknowledgement that this dominance is declining. An understanding of the dominance of the gasoline-powered car must refer to three central characteristics that are at the core of the technological regime of the modern automobile: all-steel car bodies, internal combustion engines, and multi-purpose vehicles. The following sections summarise these three elements, and provide a brief explanation of the economic and the environmental implications associated with them.

2.1. The all-steel car body

The use of steel as a specific design premise for the modern automobile has been so influential in car manufacturing that it has been regarded as a specialised technological paradigm of production. Nieuwenhuis and Wells [6–8] provide a detailed explanation of the 'all steel-body paradigm'. The body-chassis technology introduced by Edward Budd from 1914 onward was what defined the technological paradigm embedded in the modern automobile. In simple terms, by engineering a solution for the substitution of steel for wood, in order to integrate the chassis and the car body in one piece – the steel *monocoque* or *unibody*, Budd determined the scale and pace of contemporary car manufacturing. This innovation resulted in crucial product and process advantages: cars were cheaper, stiffer, stronger, more able to be made in a variety of styles, and could be painted, whilst simultaneously being cheaper on a per unit basis.

Nieuwenhuis and Wells went as far as to assert that the mass production of cars as we know it today was only possible because of this innovation, and that the system of production characterised in the popular term '*Fordism*' should more accurately be called '*Buddism*'. Although Henry Ford introduced innovative shop floor techniques in automobile manufacturing, it was done so with an essentially pre-industrial design. It was Edward Budd's technology that made possible the production of high volumes and facilitated automation in manufacturing of the modern automobile, thereby underpinning both the capital intensity of the automotive industry and the requirements of economies of scale [6].

Academics in management and organisational studies, as well as historians and sociologists of organisations, have associated the human resource management (HRM) practices introduced by Henry Ford as the key element for the mass production of automobiles. These researches have, however, erroneously equalled the techniques of production introduced by Ford with the technology of production embedded in the design of modern automobiles. The '*Buddist*' paradigm of production and consequent dominance of steel in car manufacturing also resulted in vital consequences for the future of the automotive industry. Essentially, the 'steel revolution' precluded future innovations in production processes, as well as the use of alternative materials. One of the main reasons for this relates to the high investment in manufacturing technology required for the production of all-steel car bodies. According to Nieuwenhuis [9, p. 6]:

> The Buddist paradigm involves high investments in the press shop (where steel sheet is pressed into shaped panel),

[2] WBCSD: http://www.wbcsd.org (2006, May 01).

[3] Coalition for Environmentally Responsible Economics: http://www.ceres.org/ (2006, May 01).

body shop (where the pressed panels are welded together into subassemblies and thence into a monocoque body-chassis unit) and paint shop before any products have been developed. The minimum investment in a press shop would be around €160 million. Body shop investment depends on automation levels, but can be between €80 million and €160 million. Joining the Budd paradigm therefore, involves an entry cost of at least between €560 million and €800 million, without the dedicated tooling for a particular car or model.

Such entry costs may explain the fact that between 1996 and 1998 Samsung, a Korean *chaebol*,[4] spent approximately €2.7 billion just to build and equip its car plant in Pusan, a city in the Southern part of the country [10]. In its first year of operations in 1998, Samsung reached fourth position in the Korean market, selling 41,593 of its SM5 car – an adapted version of the Japanese Nissan Maxima. But these sales represented less than 16% of its production capacity of 250,000 units per year. After having spent an estimated €5.5 billion to enter the automotive industry, Samsung Motors was acquired by Renault who resumed car manufacturing in the Pusan plant at the end of 2000 [11].

The Samsung case is a didactic example of how the definition of systems of production imposes economies of scale in automobile manufacturing. The all-steel body technology does indeed deliver the lowest per-unit costs of production compared with other materials and designs, but only when production volumes are sufficiently high to amortise the large capital investments required.

The dominance of a technological regime favouring the use of steel is not reducible to the technical advantages of the material. As Nieuwenhuis and Wells [8, p. 94] pointed out:

> Despite continuous improvement in steel-making technology and in design and manufacturing processes to transform steel into vehicle bodies, and despite the significant cost per unit advantage for steel in high volumes, all-steel car bodies are too heavy and the production technology too capital intensive and inflexible.

Of note, in the contemporary era, is the divergence between the economic incentives to the vehicle manufacturers, and the consumer and environmental benefits that could be derived from a change in design philosophy. Hence, the automotive industry is locked into a business model that gives primacy to high output, low unit market prices, and deriving revenues from the outright sale of new cars (including financing) rather than other income streams [1,12]. Given the importance of the market price, the logical choice for vehicle manufacturers is to prefer an established, stable and robust material-design technology in the form of steel. Consumers benefit from this low price, but of course pay in the form of higher fuel consumption over the lifetime of the vehicle.

[4] Chaebols are Korean industrial groups normally controlled by family clans, which tend to be vertically and horizontally integrated.

2.2. Powertrains based on internal combustion engines

Evolutionary economics, constructivist sociology, technological trajectories and quasi-evolutionary processes present explanations for the selection and diffusion of cars based on the internal combustion engine (ICE) as a key technology in modern societies (see, for instance: ref. [13]). The analysis here represents a particular interpretation of the phenomenon of the hydrocarbon society [14]. By revisiting the early developments in the oil industry, the section emphasises the close interdependence between the technologies that were central for the success of a specific concept of automobile. In contemporary debates on the introduction of fuel cell vehicles, it is often the non-availability of an appropriate infrastructure that is seen as a significant impediment: thereby emphasising the importance of the co-evolution of technological systems [15].

A basic understanding of the success of the internal combustion engine requires analysis of the oil industry. A combination of innovations and product substitution in the second half of the 19th century made the ICE not only a viable technology for power generation but also a technological option that could maintain the dominance of the wealthiest American monopoly of that time. In his remarkable study of the oil industry, Yergin [14, p. 14] summarises the main elements of this historical period in the following:

> In the first decades, the oil business provided an industrializing world with a product called by the made-up name of 'kerosene' and known as the 'new light', which pushed back the night and extended the working day. At the end of the nineteenth century, John D. Rockefeller had become the richest man in the United States, mostly from the sale of kerosene. Gasoline was sold as much as two cent a gallon, and, when it could not be sold at all, was run into rivers at night. But just as the invention of the incandescent light bulb seemed to signal the obsolescence of the oil industry, a new era opened with the development of the internal combustion engine powered by gasoline. The oil industry had a new market, and a new civilization was born.

Hence, Rockefeller's company, *Standard Oil*, transformed its eventual loss of the kerosene market in the illumination business into an even more lucrative commerce, initially with locomotive engines and then with the automobile. In the United States of America (USA), internal combustion engines powered only 22% of the cars sold in 1900: 38% were electric and 40% were powered by steam engines. The situation changed rapidly: by 1905 gasoline-powered automobiles had defeated their competitors. The number of car registrations in the USA grew from 8000 in 1900 to 902,000 in 1912 [14]. Considering that gasoline engines powered the vast majority of these cars, by any standard it represented a remarkable success for ICE technology.

The strategic importance of the automobile industry for oil producers meant that the petroleum industry had an underlying economic justification to encourage automakers to continue adapting the internal combustion engine to hydrocarbon fuels so setting in place the foundations for the petroleum and car industries to become interdependent for the remaining part of the 20th century. The intrinsic characteristics of ICE cars, as well as the advantages resulting from their use, cannot be ignored – the comparative higher flexibility and degree of independence of ICE cars certainly influenced their success. The high-energy content of gasoline and other hydrocarbon fuels resulted in relatively higher levels of drive autonomy, compared to cars powered by electric batteries. As one can envisage, in the early days of the 20th century, such advantages were even more crucial than today.

The high production volume of all-steel car bodies was coincidently matched by the economies of scale required in engine manufacturing. According to Rhys [16] the optimum scale of casting blocks and other engine parts is estimated to be around 1 million units. The production of such high volumes requires automakers to have considerable economic strength. They need to invest in resources, development and manufacturing infrastructure, as well as managerial capabilities to coordinate the development of engine components within a network of suppliers. Put simply, engine manufacturing is a large-scale business. The magnitude of production and the relative independence of engines from issues of style result in engine families remaining in production for longer periods of time than individual car models [17]. As a consequence, any changes in material specification are dependent on even longer cycles than in car-body applications. Historians of technology describe the overall result of such practices as 'lock-in' situations [13]. Understandably, for most vehicle manufacturers, abandoning the ICE-powered car is simply an anti-economic choice, once 'they are locked out of by being effectively locked in to the ICE'.

Further improvements in the efficiency of the internal combustion technology are still feasible [18], most notably shown in the introduction of petrol-electric hybrid engines in recent years [19]. Nonetheless, the pressure to improve the environmental performance of ICEs is expected to escalate in the first decades of the new millennium – witness for example the European Union's target of an average fuel efficiency of CO_2 emissions of 140 g/km by 2008 [20]. Gasoline/diesel-powered cars will be required to achieve increasingly restrictively regulated levels of emissions for cleaner air [21]. Alternative forms of automobile traction are expected to become more attractive from both an economic and environmental perspective.

2.3. Multi-purpose automobiles

The basic characteristics of the modern automobile – the all-steel car body and ICE-based powertrain – influenced the definition of a third central feature of the car design. Cars are designed to be multi-purpose, or perhaps more accurately general-purpose vehicles, able to perform various roles competently but none with great efficiency. Today, three market segments, denominate core segments, that account for approximately 70% of total sales of automobiles in Europe. Although the other 30% comprise niche market vehicles, such as four-wheel drive, luxury and sports vehicles, most of these cars can be classified as *multi-purpose vehicles*.[5] Basically, these cars can carry one to five passengers, reach speeds of more than 160 km/h (although the legal limit is 110 km/h and the average traffic speed is approximately 70 km/h), and have sufficient fuel capacity for approximately 400 km. Cars therefore, embody a high degree of redundancy in design, a feature that carries efficiency and environmental costs. Most trips do not demand such performance but the vast majority of cars currently available in the market present these characteristics. The average drive in cities – the place where most cars spend the largest part of their time – requires less than 20% of such performance capacity, and the average occupancy (1.2 people per car) is also much lower than the capacity of these cars to comfortably accommodate five people. For the vehicle manufacturers, high volumes of sales (and therefore production) are more likely to be assured by general-purpose designs that approximate to several user needs; in other words, market offerings of this type are a form of risk reduction.

One could question the reasons for consumers to keep buying over-dimensioned and over-specified cars. Simply, what could explain the success of the multi-purpose vehicle? If a smaller car with substantially reduced performance (presumably costing less than a multi-purpose car) could potentially satisfy the needs of most motorists, why do they pay relatively more for larger cars? Fundamentally, for most consumers the conceptual image of an automobile resembles the multi-purpose vehicle [22]. Although the technology embedded in conventional steel-bodied cars powered by internal combustion engines is under-utilised, this concept became synonymous with what a car should be. Consumer expectations are a powerful force limiting the scope for systemic innovation [23].

Traditionally, sport cars have been the only area of market success for two-passenger cars. Roadsters, such as the BMW Z3, Mercedes-Benz SLK 230, Porsche Boxster, and Mazda Miata suggest that preferences for two-seater cars have little to do with environmental concerns. These market successes represent a specialised niche preference associated with velocity and freedom. The case of the Smart car – a two-seater launched by Mercedes in 1997 – demonstrates that consumers have not responded so well to cars whose appeal is based upon their environmental friendliness [24]. In the case of Smart, it was only when the marketing strategy refocused to its appeal as 'fun-to-drive', and its high-tech equipment, such as formula one soft-tip gearshifts and the design of interior parts, that consumers started to respond. In fact, the continued survival of the Smart car is uncertain following the failure of a roadster that sought to compete with other sports cars [25].

The structure of the after-sales market constitutes the last factor influencing people's choices in buying multi-purpose cars. For most consumers, the relatively high economic value of vehicles transforms them into major sources of investment. Generically, average cars are easier to commercialise than those designed for specific market niches. In these

[5] The concept used here differs from the one referring to multi-purpose vehicles (MPV) eventually used in classifications of market segmentation to denominate a specific market niche.

circumstances, a car presenting the characteristics of the Smart (two seats) can expect to find only a very select number of consumers willing to buy it as a second-hand vehicle. By contrast, cars such as the Volkswagen Beetle (a multi-purpose car, according to the prerogatives presented here) became a product of high commercial value in many countries mainly because of its potential to be further traded. In fact, the characteristics of the automobile market, which currently reinforce consumer preferences, are not limited to the demand side. The current technological regime of the automobile imposes development strategies and forms of rivalry that, in many respects, are specific to the auto industry (Hekkert and Hoed, 2006). They are explored next.

3. Strategies of rivalry in the automobile industry

Vehicle manufacturers have historically considered the all-steel car body and the internal combustion engine as their core competences [8]. They mastered the technologies assisting these core competences and, in this respect, the automobile sector has achieved a great degree of maturity. Internal combustion engines have achieved an amazing degree of sophistication and efficiency [18] and the technology associated with the production of all-steel car bodies has been the main driving force in the development of robots in factories. Not only have an impressive array of technological developments been achieved during the history of the automobile but the sector has also served as a benchmark for new management strategies and skills, such as total quality management (TQM) and lean production [26]. Terms such as *Fordism* and *Toyotaism* became associated with specific management techniques, widely adopted by organisations in other industrial sectors (see, for instance: ref. [27]). Either from an economic, technological, cultural, or political perspective, the automotive industry has been a successful enterprise.

Nonetheless, there are many reasons to believe that the foundations for this historic success are fading away. Remaining profitable or exiting from the auto industry without substantial losses is becoming increasingly difficult. In recent years GM, Ford, Nissan, Fiat, Saab, Jaguar, Daewoo, Kia, VW, and Mitsubishi have reported significant financial difficulties. As a result, the imperatives of cost reduction have been imposed on component suppliers, and vehicle manufacturers have imposed a rationalisation of systems of production that extended far beyond the frontiers of the focal car corporations. Economic pressure has driven the automotive industry towards a profound process of restructuring and redefinition of its competitive strategies. The main roots and consequences of such transformations are summarised in Section 2.1.

3.1. Economies of scale, low profitability, and market saturation

Manufacturing automobiles has increasingly become a risky enterprise. Observe the recent history of the Japanese automaker Nissan. During the 1980s, Nissan was among the Japanese corporations that served as a benchmark of efficiency and quality for western firms. In 1989 the company obtained a 2.1% net return on sales of 2.81 million vehicles – still a poor performance note but in automotive industry terms a reasonable result. However, during the period 1992–98, Nissan sold an average of 2.72 million automobiles per year and the only year in which the company had net positive returns on sales was 1996 [28]. What explains such performance? How can a company sell volumes that are comparatively higher than the combined production of cars and trucks of all Latin America (around 2.5 million units) and still not be profitable?

The bubble burst of the Japanese economy in the early 1990s is certainly one of the factors influencing Nissan's performance. But it does not explain the continuous success of Nissan's rivals, such as Toyota and Honda. As one might expect, poor management practices were part of the equation. The nature of the decision-making within the vertical Keiretsu system, which bound Nissan to its suppliers, was one, among many other management practices that resulted in the accumulation of debts totalling €7.72 billion. In 1998, the French automaker Renault bought 38.6% of the company and became Nissan's largest shareholder. The new management imposed a drastic 'rescue plan', including the closure of five factories and the consequent loss of 21,000 jobs worldwide, as well as the reduction of annual capacity from 2.4 to 1.5 million cars from 2000 onwards [29].

The case reveals a central characteristic of the automotive business: the slim margins between profit and loss faced by most vehicle manufacturers. One causal factor is the imperative of economies of scale that vehicle manufacturers have imposed on themselves over the years. On a per-modal basis, a break-even point of 250,000 units per annum is considered minimum practice in the industry [30]. On a factory basis, a typical plant with a capacity for 300,000 units per annum must reach 80% utilisation to be viable.

The second factor explaining vehicle manufacturers' slim margin between profit and loss is the failure to capture the life-cycle profit streams generated by car sales, ownership and use. In all activities involving car manufacturing, retailing, leasing, servicing, insurance, finance and car parts, among other businesses, shows that carmakers take a meagre 1% of the total [31]. In terms of operating margins, car assemblers and component suppliers together have average returns on revenue of 3.5%. Not surprisingly, the combination of such margins with high break-even points for most car models makes carmakers particularly vulnerable to slight market fluctuations [31]. The saturation of mature markets in highly industrialised countries transforms this vulnerability into a cycle of profit and loss in the industry.

During the 1990s, for instance, only three volume manufacturers – BMW, Toyota, and Honda – did not experience any year of losses. In 1992, General Motors reported a loss of €26 billion on a turnover of €131 billion. Over the period 2005–6 the leading vehicle manufacturers in North America, GM and Ford, along with their primary suppliers (Delphi and Visteon) all reported financial losses, with Delphi seeking Chapter 11 protection from bankruptcy and Visteon being re-absorbed into the Ford company in order to protect the vehicle manufacturer supply of components. The Ford case is illustrative [32].

In 2002 Ford launched their Revitalisation Plan, a dramatic attempt to stem mounting losses, restore the profitability of the company, and assuage growing concerns in the financial community. It included the axing of 35,000 jobs. In January 2006, Ford announced The Way Forward, a dramatic attempt to stem mounting losses, restore the profitability of the company, and assuage growing concerns in the financial community. The plan included: The closure of seven vehicle assembly plants and seven parts plants by 2012; The loss of between 25,000 and 35,000 jobs; A reduction in manufacturing capacity in North America of 1.2 million units by 2008 (26% of existing capacity); A reduction of 12% in corporate staff, along with 4000 white collar salaried staff in the first quarter of 2006; A reduction in material costs of at least $6 billion by 2010. Ford has already provided details on three of the assembly plants to close. They are the plants in St Louis (Ford Explorer, Mercury Mountaineer SUVs); Atlanta (Ford Taurus); and Wixom (Lincoln LS, Town Car and Ford GT). In Europe, VW in 2006 raised the prospect of having to lose 20,000 jobs to remain competitive, while MG Rover finally collapsed into bankruptcy.

Overall, the automotive industry in has been marked by overcapacity and market saturation [33]. During the 1990s, the number of automobile registrations remained around 12 million cars per year [34] in Western Europe, with Japan and North America presenting similar, quasi-horizontal curves. Such a scenario certainly favoured the consumer. Higher levels of rivalry among vehicle manufacturers put pressure on prices and favoured consumer demand on a wider variety of models.

The fragmentation of markets is illustrated for the case of the UK in Table 1. It shows that in an almost static market in volume terms, the total number of variants on offer more than doubled, from 1303 in 1994 to 3155 in 2005. This market fragmentation puts intense pressure on a manufacturing system orientated towards standardised production and, alongside shortening model life-cycles, acts to undermine per-model economies of scale thereby increasing the significance of so-called platform strategies and other cost-reduction measures.

Table 1
Brand names, models, body styles and variants in the UK market, 1994 to 2005

Year	Brand names	Models	Body styles	Variants
1994	54	205	300	1303
1995	56	211	309	1580
1996	57	218	321	1624
1997	53	225	318	1611
1998	54	231	382	1637
1999	52	240	332	1759
2000	57	262	357	1931
2001	58	260	351	2042
2002	57	263	387	2472
2003	56	257	370	2743
2004	62	351	397	3042
2005	54	323	376	3155

Source: Wells and Morreau [66].

In competing for an increasingly fragmented market share, vehicle manufacturers also faced pressure to invest in product development. Simultaneously, the low profitability of the industry put pressure on them to cut costs. Recognisably, such a situation is far from ideal from the producer's point of view. The combination of the imperatives of economies of scale, market saturation, high consumer demand for a wider range of models, and low profitability margins, is not exactly a good basis to enter business.

If there is agreement about the saturation of markets, the picture is not so clear about where to locate the overcapacity of the industry. According to Wells [17], in 1996 the global excess capacity of the auto industry was equivalent to 40 average assembly plants. In 2000, overcapacity was around 18–20 million cars per year – or 30% of the total capacity of 60–65 million units per year [34]. Despite widespread closures and capacity reductions in North America and Europe, expansions in these regions and elsewhere have ensured endemic overcapacity remains an industry characteristic.

High expectations in respect to emerging markets encountered a tough reality. Problems common to most developing countries, such as a lack of infrastructure, high currency fluctuations and consequent price instabilities, and structural problems resulting from inequalities in income distribution, considerably limited the potential for projections to become reality. For instance, during the second half of the 1990s the projection of sales of motor vehicles in Brazil for the year 1999 was 2.5 million units. Such a prognosis was one of the reasons for the massive influx of automakers' investments during this period, which transformed Brazil into the country with the highest number of local market vehicle producers. However, the sales of motor vehicles achieved in Brazil in 1999 were around 1.3 million units, or only 52% of the forecast. In 2006, Latin America overcapacity is similar to those of mature markets.

3.2. Rationalisation of systems of production

Rationalisation of systems of production has been one of the main responses by firms in the industry. Fundamentally, vehicle manufacturers have to explore every cost saving opportunity to maintain their competitive edge and profitability margins. Although the peculiarities and capabilities of each producer determine how they implement their cost cutting measures, the main areas of common action that have emerged in the last decade include platform consolidation and modular assembly.

3.2.1. Platform consolidation

Although there is no common concept of what constitutes a 'platform', in its essence a platform is the 'floor' or the foundation of a vehicle along with the major components such as suspension sets. When car models use different platforms, they require dedicated engineering, general tooling, and assembly elements. The idea of sharing platforms is, therefore, a simple one: a lower number of platforms for a vehicle manufacturer across their range means lower costs. In the 1990s industry experts believed that platform consolidation could represents savings of between €55 million and €110 million in body welding alone in a car plant but savings can also be achieved in engineering, testing and tooling [35]. Fundamentally, this is the main rationale fostering platform consolidation, which the automotive industry has pursued vigorously from the second half of the 1990s onwards. Vehicle manufacturers have put substantial efforts into reducing the total number of platforms but, in order to accommodate market fragmentation, a large number of models and variants have been derived from a single platform – particularly by multi-brand groups (such as GM and Ford) where a portfolio of market-facing brands is held in common ownership.

Platform consolidation should be understood as a management strategy, rather than an innovative design for production systems. In fact, the concept of a common platform is as old as the automobile. By the 1920s, vehicle manufacturers were using similar techniques aimed at economies of scale. However, increasing consumer demand and rivalry within the industry resulted in a substantial growth in car models for several decades. Satisfying consumer demand for new models was relatively more important than the rationalisation of platforms. In the 1990s, the situation reversed. Many markets became saturated and the investment costs of new platforms simply could not be maintained by vehicle manufacturers. Rationalisation of systems of production became an imperative 'correction' of manufacturing strategies that could only be maintained in the 'old times' of substantially higher demand for cars and less pressure on cost reduction. In the late 1990s, there was an unequivocal race for the best performance, measured by the total number of cars of different models produced with a single platform. Volkswagen topped the list in 1999. The German company used a single platform for the production of eight different models whose combined sales totalled 1.9 million units [30].

Extreme platform rationalization may result in cars ending up looking too similar. Consumers of relatively more expensive car brands may not appreciate the fact that the automaker uses the same platform to manufacture lower-ranked cars [36]. This is the case with the Audi A3 and Audi TT, which share the same platform as the VW Golf and Skoda Octavia. Such market-driven obstacles limited the expansion of rigid platform consolidation, leading to the emergence of so-called 'architectures' in the early years of the new millennium. Hence, 'architectures' emerged as another attempt to gain commonality alongside variation [37], while further cost savings were pursued in other aspects of car manufacturing, such as modular assembly.

3.2.2. Modular assembly

Suppliers of vehicle components have played progressively more important roles in cost savings strategies in vehicle manufacturing. The search for hidden opportunities for cost cutting moved from the components themselves to the management of the interface between components and car assembly. In other words, the suppliers become actively involved not only in the design of components but also participate in the assembly process. With this method, known as *modular assembly*, firms supplied not only components but also entire sub-assemblies, fitting them in the assembly lines.

An example of modular assembly can be found in the city of Resende, in the state of Rio de Janeiro, Brazil. There, seven suppliers collaborated with Volkswagen to build a truck plant. The component suppliers employed three quarters of the factory workers that participated directly in the truck's final assembly. Similar practices were adopted in 'Smart Ville', the industrial facility where the Smart car is assembled in Hambach, France. Rather than assembling the entire Smart; the Micro Compact Car company (MMC) sub-contracted large sections of the assembly plant to suppliers, whom they designated as 'system partners'.

The direct participation of suppliers in investments in new plants reduces the need for capital directly invested by the vehicle manufacturer and improves sequencing of component flows into production. However, such attempts to integrate the supply chain seem to have a more managerial rationale. The management of a more integrated system is certainly less costly for automakers. By dealing with a smaller number of suppliers, long-term relationships can be better established, and cost-cutting strategies can be based on a more collaborative character.

3.3. Industry consolidation: mergers and acquisitions

In terms of ownership, the automobile industry in 2006 was to differ significantly from the situation in the second half of the 1990s. The intercontinental merger of the American *Chrysler Corporation* with *Daimler-Benz* of Germany in May 1998 represented a milestone in the history of the automotive industry. Thereafter, the pace of mergers and acquisitions became even greater. Observe the amusing summary of the consolidations that occurred in the period 1998–2000, as presented by Feast [38, p. 34]:

> Ford snapped up Volvo Cars and now Land Rover, Volkswagen bought Bentley, BMW will own Rolls-Royce from 2003, Audi acquired Lamborghini and Hyundai Motor won control of the bankrupt Kia Motors. Rover was put down. Renault raced to the rescue of troubled Nissan and Dacia and now wants to take over the bankrupt Samsung Motors. Daewoo Motor won the battle for Ssang Yong Motor, only for the whole Daewoo group to collapse. Now Daewoo Motor itself is on the block, with Fiat, GM, Ford and DaimlerChrysler eager to pick up the pieces. DaimlerChrysler itself appears close to a merger with heavily indebted Mitsubishi Motors. Whatever next?

Experts in the industry seem to agree on the size imperative. That is, in order to compete in this brutal business [34], car manufacturers need to have global reach. In the view of O'Brian [39, p. 56]:

> Mergers and takeovers among assemblers are designed to achieve economies of scale and scope; strengthen positions in certain markets, including though brand reinforcement; and, in some cases, to provide access to a better mix of labour than was previously available to the stronger firm.

Globalisation has supposedly become the key word behind the trend of mergers and acquisitions. Indeed, many industry analysts believe that this is the only strategy for survival in the auto business. If the current trends of consolidation are maintained, by the year 2020 only six vehicle manufacturers, each one producing around 15 million units per year, will remain in the industry [38]. In practice, these multi-brand groups failed to achieve the synergies and cost-savings intended, indeed they showed instances of diseconomies of scale. As a result, for example, GM had to buy its way out of the 'put' option held by FIAT that could have forced the US vehicle manufacturer to take over the Italian firm. Equally, BMW divested itself of the troublesome MG Rover Group, while DaimlerChrysler sold its interests in Hyundai and Mitsubishi.

According to Rhys [16], opportunistic takeover is a risky business. The high number of failures in mergers is a result of acquisitions that had not considered the fundamentals of the businesses purchased. Wells and Nieuwenhuis [40] suggest that the problem does not lie in the fundamentals of the businesses but the overall assumption that bigger corporations will have a better chance of surviving in the industry. Indeed, concentration of capital and ownership reduces the risks of exposure to localised market fluctuations, and increases the capacity of carmakers to invest in research and development as well as marketing. However, the authors stress that economic, social, environmental and new enabling technologies are making a new structural configuration of the industry possible. Escalating environmental pressures have the potential to accentuate the economic constraints faced by the auto industry to such an extent that, eventually, a new technological regime for the automobile may emerge. The next section explores the main problem-areas that might lead to such radical changes.

4. Environmental issues in the automobile industry

The scope of environmental harm caused by cars is vast. According to the German Environment and Forecasting Institute, before an average car is put into use, it has already produced 26.6 tonnes of waste and 922 m^3 of polluted air [41]. Although this is a significant figure, it represents less than 10% of the total environmental impact of an automobile during its life-cycle. About 80% of its impact results from air emissions during car use, the remaining 10% being due to the pollution associated with the final disposal of its constituent parts [42]. Overall, the automobile constitutes an example of a product with an extensive environmental footprint in all phases of its life-cycle. Table 2 provides a simplified overview of the environmental impacts caused by automobiles during their complete life-cycle.

Technical information about the impact of automobiles on the natural environment, described in Table 2, is readily available.[6] Graedel and Allenby [2], for instance, produced a remarkable account of the environmental impact of the entire automotive system. The authors provide detailed information not only about its impact in all phases of its life-cycle, such as energy consumption during car manufacturing as well as details of in-service phases, infrastructure needs, and recycling techniques, but they also suggest alternatives for improving the current system. Hence, it is because of the availability of this material that this section focuses more on specific issues, rather than exploring all areas in which the automobile impacts on the natural environment.

4.1. Interdependencies and trade-offs in the life-cycle of cars

If at all possible, a study concerning the environmental impact of automobiles should follow the recommendations of Graedel and Allenby [2, p. 78]:

> One should consider the extraction from their reservoirs of the materials that are used, what happens to them (and the environment) during product manufacture, how the use of the product or systems affects the world within which the use occurs, and, finally, what happens to the product or system and its materials once it is obsolete or the consumer disposed of it.

Clearly, such a study requires an analysis of environmental impacts happening in all phases of the product's life-cycle. Although this remark is of critical importance, there are two other central reasons for using a product life-cycle approach when analysing the environmental impact of automobiles.

Table 2
Simplified car life-cycle environmental impact

1	*Pre-Assembly*
	Mineral extraction for raw material (iron ore, bauxite, oil, etc.); transport of raw materials
	Production of secondary material (steel, aluminium, plastics, etc)
	Transport of these materials to assemblers and suppliers
	Production of components and subassemblies
	Transport of components and subassemblies
2	*Assembly*
	Energy used in assembly plant
	Pollutions caused in assembly process, particularly in paint shop emissions
	Release of waste materials into ground and water and into the recycling system
	Transport of finished vehicles to customer
3	*Use*
	Energy used for driving
	Pollutions caused by emissions and waste materials from disposables (batteries, tyres, oil, etc.)
	Land-use requirements (roads, fuel stations, parking facilities, etc)
	Accident damage to people and environment
4	*Post-Use*
	Transport to dismantling site/scrap yard
	Energy use in dismantling/scrapping processes
	Pollution caused by dismantling/scrapping processes
	Transport of recyclates

Source: Nieuwenhuis and Wells [8].

[6] See, for instance: the research reports of The Economist Intelligence Unit on 'the automobile industry and the environment', such as the series of environmental reports of FT Automotive. Substantial information is also available on the Internet. The Environmental Defence, an American NGO, for instance, presents a basic life-cycle analysis of the impact of automobiles: See: http://www.environmentaldefense.org/ (2006, May 01).

They both relate to the interactions that occur between phases, rather than the impact associated with each stage of a car's life-cycle (see, for instance, the work of refs. [43] and [44], in this *Special Issue*). First, there are interdependencies between the various phases of the product lifecycle, and technical innovations in one phase have the potential to either reduce or increase environmental impacts occurring in other phases. For instance, the specification of extruded-coloured plastic for the body parts of the electric vehicle called '*Think*', resulted in the elimination of painting from the manufacturing processes [45]. The elimination of this harmful production process through product redesign significantly offset any environmental gains achievable through incremental innovation in painting. In this case, analysis focusing only on environmental innovation during manufacturing would be misleading, since the most significant gains would have been 'hidden' in the design phase of the product.

Another reason for considering the entire life-cycle of a product in environment-related research relates to the potential *trade-offs* between distinct phases. In simple terms, environmental gains in one phase can represent a loss in another. The substitution of plastics for steel can result in the reduction of weight and consequent fuel consumption during the use of a car, but higher rates of non-recyclable car parts can negate the environmental gains in fuel economy [46]. If the analysis of vehicle environmental performance is not based on a life-cycle perspective, ecological improvements in car design can be misleading. These fundamental examples highlight the complexity of environment-related issues in the context of the automobile and the need to adopt a product life-cycle perspective when tackling such issues.

4.2. Materials and the environment: steel, aluminium, plastic, and other materials

Central to the issue of vehicle fuel consumption – and consequent air emissions of toxic gasses and carbon dioxide (CO_2) – is the weight of automobiles. It is here that the dominance of steel in car manufacturing suffers its biggest potential threat. The greater density of steel, when compared with aluminium or plastic composites used in similar applications, results in relatively higher energy requirements during car use. In simple terms, heavier vehicles consume more fuel.

Seventy years or so of investments in all-steel car body technology work against a move away from steel. Although the automobile sector represents only 16% of the steel market in OECD countries (Organisation for Economic Cooperation and Development) it represents upwards of 35% of output for many of the high-value wide-strip mills in the established markets [17]. For this reason, during the 1990s, the sector put substantial efforts into the Ultra Light Steel Auto Body (ULSAB) project representing a €23 million investment.

In the aluminium sector, the base percentages of the market fractions are smaller. Producers of aluminium have succeeded in increasing the content of the metal used in cars from around 3% in the 1970s to 8% in the 1990s, mainly in non-structural applications (Weernink 1998). Engine castings represent half of the total consumption of aluminium while wheels count for around one quarter [17]. While this represents a steady increase in the use of aluminium in cars, there exist exponential opportunities for growth in the use of the material for structural (especially body) applications.

In the battle between aluminium and steel what, increasingly, has been at issue has been the trade-off between the environmental impact of material inputs in production compared with their impact in-use, and a trade-off between economic and environmental cost. Aluminium producers argue that the substitution of one tonne of aluminium for steel in automotive applications would reduce CO_2 emissions by 20 tonnes over the life-cycle of an average vehicle. The steel industry argues that producing one tonne of virgin aluminium (primary production) generates 10–15 times more CO_2 emissions than producing one tonne of steel.

The dispute between the aluminium and steel industries on this matter can be simplified by identifying an 'energy break-even point', which represents the energy consumption of steel or aluminium through the entire life-cycle of a car. The steel industry has used the results of research conducted by the Materials Systems Laboratory at the Massachusetts Institute of Technology (MIT) to argue that, because the primary production of aluminium results in higher emissions of CO_2, cars with high aluminium content also have a high break-even point. The MIT study compared the total CO_2 emissions associated with the production and fuel use of both materials for: (i) a typical vehicle; (ii) a vehicle with an aluminium body; and (iii) the ULSAB (Ultra Light Steel Auto Body) vehicle. The results show that, when compared with a contemporary all-steel car body, the break-even point for the car with aluminium body is 10 years of usage, and 12 years for the ULSAB vehicle.[7]

Nonetheless, the results of the MIT study would change dramatically if one considered aluminium produced from post consumer materials or scrap alloys. The secondary production of aluminium (recycling) requires only 5% of the energy needed to produce primary aluminium from raw materials [47]. But current material availability limits the levels of secondary production. In the USA there is a well-established infrastructure for collection and recycling of aluminium beverage cans, which are used to manufacture vehicles cabs, among other products. However, the separation of specific alloy types suitable for extrusion and/or pressing still represents a problem. In most countries, systems for collection and recycling of aluminium are not as developed as those established for steel during the decades of its dominance of in car making. Additionally, low levels of recovery and consequent fluctuations in price impose serious limitations in the availability of material for secondary production.

Simply, the structure of both the steel and the aluminium industry favours the former. The interdependency between the structure of the industry and the prices of its key input commodities is highly significant. Especially, this is true of the

[7] Calculated for an average life-cycle of 12.5 years, a total drive of 224,015 km, corresponding to 17,921 km/year. See: http://www.worldautosteel.org/ulsab/index.htm (2006, May 01).

infrastructure for material recovery and recycling. The quality of this infrastructure can either foster or inhibit the *greening* of industrial sectors. Similar interdependencies are also present in another area of environmental dispute in the automobile industry: the central role of oil and petrol pricing strategies.

4.3. The 'ecological maturity' of automobiles

Although the automobile industry is a mature economic sector, the technologies associated with the current automotive system suggest that the automobile, as an industrial product, may not have yet reached its maturity. Generally, product designs evolve and change over long periods of time, through phases of experimentation, consolidation, maturity, and further innovation or decline [48]. In order to have environmental benefits, products have to evolve from experimental designs into 'maturity'. According to Roy [49], the rate and extent to which eco-designs go through evolutionary phases, depends on technical, commercial, market, and socio-political factors. For a product to succeed, going from experimentation to maturity phases, it is necessary for the product to achieve positive attributes in terms of most of the factors mentioned. The main barrier to the use of products, however, is not the design itself, but the lack of an appropriate context for its adoption. Restrictions on the use of a mature product, such as a bicycle, for instance, are more a function of lack of cycling facilities, safety problems, and the dominance of the automobile, rather than design difficulties or problems intrinsic to the concept.

Several initiatives have addressed the ecological efficiency of automobiles and related production systems. Rating schemes, such as the 'Green Book', presented by the American Council for Energy Efficient Economy, or the 'Green Index' of the California based Advanced Transportation Consortium, can indicate the leaders and laggards of the automotive industry in terms of fuel use and air emissions. However, being the leader in such rating systems does not imply leadership in environment-related vehicle innovations. In terms of environmental efficiency, today's automobile is in its infancy. Although the internal combustion engine is remarkably efficient in terms of its genesis as a technology system [18], gasoline-powered vehicles are extremely inefficient in terms of the extent to which they convert resources into appropriate energy [50,51]. The '*hypercar*' concept advanced by Lovins requires radical changes not only in the design of cars but also in the overall structure of the industry. According to Lovins et al. [52], vehicle manufacturers have considered the hypercar concept seriously (for the GM example, see ref. [53]). During the period 1993–1998 the industry committed €5.8 billion to developments on the lines of this new concept. But such changes, although technically possible, encountered a series of obstacles. They relate to the socio-technical context of the industry.

5. The socio-technical context of the car industry

The signs of stress and potential sources of structural change for the automobile industry have roots in many locales that do not encompass the traditional concept of an 'industry'. A new understanding of what constitutes the 'context of automobiles', or the *automobile field*, as is explored in this section, seems necessary. During the history of the automobile industry, examples are broadly available of how the sector, when faced with the task of overcoming its own structural inertia, was able to do so (see for instance, the account of Orsato et al. [54] about the efforts of the industry in delaying the implementation of regulations on end-of-life vehicles in Europe). Organisational size, type of structure, strategy, sunk investments in systems of production, and the imperatives of scale, can work as impediments to radical changes [55].

The loss of market share by American car companies to their Japanese counterparts during the 1980s is possibly the most debated topic in this respect. The lack of openness towards other 'ways of doing things' was very costly for the American automotive industry. It was only after significant expenditures in research, re-training of the workforce, and redesign of production systems, that the industry partially regained its former market positions in the 1990s. For the purposes of this article, there are important lessons to be learned from the loss of competitiveness by American vehicle manufacturers in the 1980s, the problems faced by some Japanese vehicle manufacturers such as Nissan and Mitsubishi during the 1990s, as well as current challenges faced by GM and Ford.

5.1. The 'automobile field'

The behaviour of consumers as well as the disputes between suppliers of steel and aluminium denotes the complexity and scope of factors influencing the structure of the automotive industry. The increased role of the use of electronic components, alternative plastics, and the potential of hybrid and battery electric or fuel cell powertrains to substitute for the traditional internal combustion engine (ICE) have increased the chances of success for new entrants in the automotive industry in the last few years. Traditional manufacturers, or at least those of them still surviving in the 21st century, remain key players in this sector.

The recent history of the industry requires one to recognise changes in the relative importance of some players. Suppliers of electronics, for instance, have become substantially more influential over the past few years. Moreover, the potential of new entrants to become central payers in the industry is acknowledged by many industry experts. According to Nieuwenhuis and Wells [8, p. 3]: "the automotive industry is indeed a vast area of economic endeavour, and to focus the analysis only on the vehicle manufacturers would be to miss the majority of the industry". In this respect, the understanding of the industry requires the consideration of emergent players, as well as the socio-technical dynamics coupled to their eminent entrance into the automotive business.

Analytically, the concept of '*organisational field*', from which the concept of an '*automobile field*' is inspired, appears to encompass the context in which the ecological modernisation of the automobile industry might occur [55,56]. DiMaggio and Powell [57, p.148] defined an organisational field as "a recognised area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organisations that produce similar services or products.'' The idea of an organisational field differs slightly from the definition of industry or sector, since it also includes institutional elements that can influence the structuring process of firms and industries that are not recognised in classic definitions of industrial sectors. The concept includes both objective and subjective factors that shape the context in which innovations might occur. Scott and Mayer [58] assert that the concept of organisational field has emerged as a critical locus of study bridging organisational and societal levels. The analysis of environment-related innovations in the specific context of the automobile industry requires such linkage [45,51].

The importance of adopting a specialised concept of organisational field for the study of the automobile industry has direct implications for the introduction of radical innovations. These need not occur in the existing industry. The organisational field may be transformed in ways in which the existing industry members are not cognisant because they are locked into their traditional viewpoints [59,60]. As the next section suggests, the technology embedded in the automobiles of the near future might depend on software expertise more than on the suppliers of mechanical parts. In this respect, limiting analysis to current market leaders might lead one to miss the most important elements influencing structural changes in the sector [60]. Outsiders have been gradually reconstructing the field of the automobile. The case of the *hypercar*, described in Section 3.3, shows that one needs to consider not only innovations undertaken by vehicle manufacturers but also technological and market experiments conducted by those who, in the near future, might dictate the pace of innovation in the industry.

5.2. Core competences in the automobile field

The notion of an automobile field is fundamental when one considers the potential of radical innovations to trigger structural changes in the industry. When Prahalad and Hamel (1990) proposed the concept of core competences, they attacked the tendency managers have to perceive their business units and products as the most important management assets. The authors emphasised the importance of decoupling from the specific reality of the strategic business units and concentrating on assets that can generate long-term competitive advantage, normally of intangible nature. Prahalad and Hamel [61, p. 81] stressed: ''in the long run, competitiveness derives from an ability to build, at lower cost and more speedily than competitors, the core competences that spawn unanticipated products''. Technologies such as *mechatronics*, video display, bio-engineering, and micro-electronics were cited as examples of corporate core competences that might eventually be transformed into a competitive advantage by firms.

Most automakers have historically considered the manufacture of steel-based cars and internal combustion engines as their major core competences. In the light of the concept proposed by Prahalad and Hamel [61], viewing the production of car bodies and engines as the core competence of automakers represents, fundamentally, a misuse of the concept. A fair use of the concept would, possibly, result in vehicle manufacturers positioning themselves as 'manufactures of propulsion systems', or even as 'suppliers of mobility' or 'systems integrators'. In such a view, they would not be 'locked into' a specific technological option, as it is the case of ICE-based powertrains. The factual possibility that a vehicle can be based on technologies that differ substantially from those of today's cars suggests that those corporations that do not move away from such competences might not be able to survive in the near future.

Indeed, more than four decades ago, Kuhn [62] already provided evidence from the history of science to suggest that radical innovations have a better chance of being initiated by 'outsiders' to a paradigm by which a professional field guides its actions. Specifically, in relation to the field of the automobile, Lovins [50] and Truffer [63], among others, claim that the innovative *milieu* with the potential to transform the industry's paradigm have a better chance of occurring in areas outside the industries existing boundaries.

There is another justification for establishing a link between the product (the automobile) and the field embedding its systems of production and consumption. Since the auto industry is a consequence, rather than a cause, of the invention of the automobile, systems of production essentially reproduce the outcomes of earlier theoretical conceptions about what should constitute a car. These become embedded in the design parameters and assumptions framing the production paradigm – they become deeply embedded in the materiality of the paradigm. Thus, production processes, factories, and entire industries are defined and designed *after* the conception of the vehicle. In a potential future, capitalism might properly value service and preserve the natural capital of ecosystems rather than regard it as a non-issue that demands little or no attention (see: ref. [52]).

In such a scenario a 'Natural Capitalism' might well prevail, in which the core competence of automotive companies could be based on know-how as diverse as telematics, hydrogen-powered fuel cells, or modular manufacturing management. The potential for such changes to occur seems sufficiently rational for Nieuwenhuis and Wells [8, p. 4], to pose the question ''how, and to what extent, an existing and established socio-technical paradigm may change fundamentally in the light of growing pressure, leading to dysfunctionality and, ultimately, collapse''? In other words, the main issue surrounding the automobile field relates not to whether structural changes will occur but identification of the factors that can spur the changes and the characteristics of this transformation.

Importantly, the automotive industry does not exist in a world of its own. Notwithstanding the previous discussion on the linkage with the petroleum industry, world events can and do have significant repercussions for the automotive industry as demonstrated by the Bush administration reaction to the events surrounding the attacks on the World Trade Centre, New York in September 2001. Suddenly, oil security and the reduction of dependence upon imported oil became matters of overt national security, thereby bolstering research into alternatives. This process is still unfolding, but demonstrates clearly how the 'rules of the game' can shift.

6. Conclusion

There are no doubts that improvements have indeed been made by car assemblers. The average environmental performance of most fleets has significantly improved in the last quarter of the 20th century [2]. Such improvements, however, have not alleviated the pressure faced by firms operating in the industry. Regulatory measures on air emissions have continuously intensified. During the 1990s, the industry has successfully lobbied against the imposition of direct regulations on end-of-life vehicles [54]. Despite this, the European Parliament approved a new Directive on ELVs in September 2000 [64]/this issue, [65]/this issue, [54]. In order to satisfy standards of environmental performance, the industry has also been obliged to invest increasing amounts of money in increasingly expensive research and development activities. Environmental issues have certainly become an important economic issue for the automotive industry. In the future, other issues may emerge with equal transformational power: for example growing levels of motorisation in emerging economies has also resulted in an estimated 1.2 million killed and 50 million injured per annum, with the expectation that road traffic accidents will be, by 2020, the third largest single cause of global health problems as measured by disability adjusted life years [67].

Automakers have responded to the regulatory and market pressure but the technological paradigm orientating car design and manufacture substantially limits the alternatives available to them – perhaps explaining the more positive attitude towards hybrid powertrains compared with fuel cells over the period 2000–2006.

As we explored in the article, a shift away from the current all-steel, internal combustion engine car requires automakers to fundamentally reform their systems of production [56] – something not so easy for those who have sunk investments in current car manufacturing technology. This and other factors explain why eco-oriented innovations in the automobile industry are to have an incremental, rather than a radical, nature [60]. Further improvements in the current technological regime can certainly reduce the environmental impact of current automobiles. These incremental advances, however, represent the last gasp of an outdated technological option, which may eventually be replaced by ones capable of significantly increasing the energy efficiency of vehicles, as well as reducing their environmental impact. The market successes of more environmentally sound vehicles require more than technological ingenuity; it requires the reformation of the institutions compounding the *automobile field* – socio-technical context of the automobile industry.

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