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Disrupting the Business of Producing Automobiles: Technologies for Cleaner Production

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Abstract

The concept of innovation has been used in a wide range of contexts and the theoretical development has proven to be extremely valuable to provide important insights into intra-market competition and strategy. The automotive industry offers a fertile terrain for the progress of the uncompleted theory building process of innovation, especially with the introduction of alternative fuels and alternative powertrain technologies. The application of these concepts is fundamental for the sustainability of the entire industry.

This paper will look at the concept of innovation in the context of the modern automotive industry focusing on the notion of regulatory innovation of alternative fuels and alternative powertrain. For the purpose of analysing this issue, special attention will be given to the concepts of radical and incremental innovation, which will be applied to existing alternative fuels and alternative powertrain technologies, including hybrids, biofuels and hydrogen power. The article will explore these three categories looking at representative case studies: the Brazilian ethanol experience with biofuels, the development of the Toyota hybrid vehicle and the technological development of hydrogen fuel cells.

Keywords: *Automotive Industry, Alternative Technologies, Innovation, Biofuels, Hybrids, Hydrogen Fuel Cells.*

1. Introduction

Despite of the economic importance of the automobile, incumbents have been suffering from pressures that threaten the economic long term sustainability of the majority of traditional firms. Not only has the product been questioned on environmental and safety grounds but the financial and economic situation of incumbent firms has been the subject of great concern. Despite of the fact that this work will focus on the application of alternative fuels and alternative powertrains to the innovation discussion, the economics of producing vehicles in large scale plays a fundamental part in the modern competitive terrain.

The mass production automobile is characterized by the all-steel-body structure and the use of petrol-fuelled internal combustion engines. These technologies constrain firms to extremely large initial capital investments, which are mostly sunk costs that need to be recovered with high number of units sold. This constitutes a trap as each competitor has to sell a considerable large amount of vehicles in order to reach a break even point. Another fundamental point is that the global automotive market has very high barriers to entry for new competitors, making it a high concentration market. The recent trend of acquisitions and mergers has contributed to form larger groups that blindly rely on the economies of scale.

2. Innovation

The wide variety of definitions of innovation has resulted in vagueness of terms and explanations (Garcia and Calantore 2002). With the intent of avoiding misunderstandings, we had opted to build on the core approach originally presented by the Motor Industry Research Unit within the detailed state aid regulatory context of the European Community (Bhaskar 1988).

The well established notion of the *Christensen's effect* is illustrative of the potential treat that incumbent firms are exposed in a market with innovations (Christensen 2006). Chistensen's work is focused on a description of how successful firms fail with the introduction of disruptive innovations. In this context the distinction between sustaining and disruptive technologies is crucial. Sustaining technologies are the ones that improve the performance of established products, along the dimensions that mainstream customers in major markets value. Disruptive innovation refers to a new technology that emphasizes innovative attributes and qualities that are significantly different from those valued by the mainstream market segment. When disruptive innovation is firstly supplied to the market it only appeals to a small share of consumers. With further technological development and greater information, mainstream consumers change their preferences and the conventional products that once were the most satisfying ones become less attractive (Christensen 1997). This process leads in due course to the innovator's dilemma, where incumbents have to decide if they should allocate their resources on the traditional processes and technologies that they are familiar with or to invest in new technologies that could be potentially disruptive.

Another fundamental concept is radical innovation. Utterback (1996) defines radical innovation as a discontinuous change that sweeps away much of the firm's existing investment in technical skills and knowledge, designs, production techniques, plant and equipment. The significance of radical innovations is that they do not address a recognized demand but they create a demand previously unrecognized by the consumer, resulting in a new market infrastructure (Colarelli 1998). Radical innovations present both macro level innovativeness characteristics as the product is new to the world, the market and the industry, and micro level characteristics, as it is novel to the firm and consumer (Garcia and Calantone 2002).

Rogers (2003) presents aspects that distinguish disruptive innovations from those that are radical in nature but not disruptive. The radical nature of the innovation is related to the technological dimension while the disruptiveness has to be related to the market effect to the incumbents. Disruptiveness can be technological less-radical or technological more radical but is necessarily related to the phenomenon of the consumer changing tastes and switching from the mainstream product to the new one. Christensen's early work, for instance, was focused on low-end disruptions (Christensen 2006).

In this respect, there is a clear difficulty to use analytical tools to identify disruptive technologies as the measure of disruptiveness is ex-post in nature. Danneels (2004) points out that it is not possible to clearly provide ex-ante definitions of disruptiveness, following all the characteristics defined by Christensen. The definition is fundamentally influenced by the organizational-level abilities and competences. The most important models do not provide rigorous forecasting capacities (Govindarajan and Kopalle 2006). In this sense, in this work we have opted to conduct the analysis on the observable ex-ante characteristics of the nature of the innovation focusing on the radical innovation concept.

3.1 Regulatory Innovation

A specific example of the innovation discussion in the political realm involves the interpretation of state aid regulation in the European Community in the late 1980s and early 1990s. Here, while state aid was permissible for innovation, it was not permissible for mere modernisation and member states could be challenged if in breach of this. An attempt was made by the research team at the Motor Industry Research Unit (Bhaskar 1988) on behalf of the European Commission's Directorate General IV (Competition policy) to define innovation within the specific state aid regulatory context of the European Community, in particular how this applied to the automotive sector. The European car industry at this stage was thought to be suffering from a competitive disadvantage vis-à-vis the Japanese car industry. A catching up exercise was in progress whereby European car makers gradually adopted 'lean' car manufacturing technologies and methods as exemplified by the Toyota Production System (cf. Cusumano 1984, Womack et al. 1990). The definition that was used in this context was: *The operation, on an industrial basis, of a new system or process which, in whole or in part, represents a significant step forward for a particular industry in terms of product quality, cost savings, or the safety of the workforce*. (Bhaskar 1988: 2).

This definition, which was broadly accepted by all stakeholders, allowed the EC automotive industry to be identified as "a particular industry". This then also allowed the adoption of innovations from outside the EC (e.g. Japan) to be interpreted as innovative within the context of the EC automotive industry, but only in so far as it constituted a first application within the EC. However, it was also recognised that two competing EC firms may be working on introducing the same innovation at the same time. It was considered unfair if only the firm who managed to introduce it even a day before the other was able to benefit from being classed as innovative under the state aid rules. For this reason, the report proposed a period of twelve months within which such innovations could be considered as being concurrent, while beyond this period the next introduction would be classed as modernisation rather than innovation (Bhaskar 1988: 4). This approach represents a more practical notion of innovation as it moves beyond the pure academic and theoretical into the regulatory and policy-making areas. Such notions are important when it comes to explaining the behaviour of the automotive industry in the face of more sustainable alternatives, as we explore below.

3.2 The Cost of Innovation

The mass production car industry is a highly capital intensive sector and decisions are made largely on their capital intensity. This also means that the existing cost consequences and amortisation of sunk costs are key elements in any decision regarding future technology choices. Thus if an alternative automotive energy source requires either the creation of very high new capital-intensive systems, or the premature abandonment of existing high capital-intensive systems, it is likely to meet considerable resistance from the industry. If on the other hand, such an alternative energy source can be used within the existing capital investments, its chances of being accepted by the industry are so much higher. We are here using a broad definition of capital investment, which also includes investment in skills and expertise in both the R&D and product development areas, as well as in production.

For this reason, the distinction between alternative fuels and alternative powertrain is not a trivial one. We would argue that an alternative fuel is an energy source that can be used with no or minimal modification in existing engines. Alternative powertrain on the other hand, replace the existing internal combustion engine with a different system, thus rendering existing sunk investments in internal combustion engine technology obsolete and requiring new investments into a different manufacturing system for a different type of powertrain. Again this would also involve hiring or training engineers with expertise in these new and different technologies, whilst making that expert in the abandoned or replaced technology redundant. This is the key distinction, whereby we would class alternative fuels as incremental and alternative powertrain as radical innovation. Thus, when reviewing existing alternatives, we can categorise them under two separate headings, as set out in table 3.1.

It is clear that internal-combustion electric hybrid technology adopts an unique position. On the one hand, it uses existing fuels – currently petrol – although it can be used with LPG, CNG or biofuels as well, while diesel hybrids are under development, by among others PSA Peugeot-Citroen. This is due to the fact that the hybrid system is driven by an internal combustion engine with all the advantages and disadvantages this entails. However, it could also be categorised as alternative powertrain, as the electric drive elements are more similar to those found in a battery-electric or even a fuel cell electric vehicle. However, the key issue is that existing car makers involved in this technology choice, notably Toyota and Honda, have not had to abandon their existing investments in internal combustion engine manufacturing technology. They have merely had to add another element to the established internal combustion powertrain, thus safeguarding their sunk investments. In this sense, it is therefore – from the point of view of a car manufacturer – more akin to adapting an existing IC engine to run on alternative fuels, rather than replacing an existing powertrain manufacturing system with a different system altogether.

Table 3.1: Alternative fuels v Powertrain : Incremental v Radical Innovation

Technology	**Incremental innovation**	**Radical innovation**
LPG	*	
CNG	*	
Biodiesel	*	
Bioethanol	*	
Hydrogen IC	*	
IC-electric hybrid	*	
Battery-electric		*
Fuel cell		*

Similarly, the case for hydrogen is split. If the hydrogen is to be used to power a fuel cell, we are dealing with alternative powertrain and this with radical, disruptive technology. If on the other hand the hydrogen is used to fuel an internal combustion engine, as proposed by BMW and Mazda, among others, we are dealing – from the point of view of car manufacturers at least – with an incremental technology, an alternative fuel. It is for this reason – relatively minor disruption – that these car manufacturers are promoting this type of hydrogen technology.

Amory Lovins has pointed out in the past that car makers think like accountants, rather than economists: "They are prisoners of enormous sunk costs which they treat as unamortized assets, substituting accounting for economic principles…This mindset is a critical obstacle…new ways cannot diffuse without displacing old ones that resists with distinctive vigour" (Lovins et al. 1993: 17). Safeguarding existing investments until fully amortised is a key concern of the car industry. This explains the industry's comparative willingness to embrace hybrid technology, but also its reluctance to do the same with fuel cell technology. From the policy-making point of view, therefore, considerably more can be achieved by regulating in the direction of alternative fuels and incremental innovation, than alternative powertrain and radical innovation. At the same time, research into such more radical initiatives may be encouraged and supported, thus reducing the risks. To illustrate these points, we will now review a number of these alternatives and analyse the regulatory and industry responses to them.

4. Alternative Power train technologies

4.1 Biofuels – The adoption of Ethanol in Brazil.

Biofuels have historically been an alternative to the fossil derived fuels. Despite of the pioneering use of ethanol in several models (e.g. Model T), it did not become the mainstream fuel. However, the most successful large-scale experience with the adoption of biofuels has taken place in Brazil, with the sugar-cane derived ethanol fuel. In November 1975, the Brazilian government established the *Proalcool* programme to foster the adoption of ethanol as a substitute for the imported oil. The first oil crises of 1973, had been particularly harsh on the Brazilian economy distorting the internal balance of payments and stimulating high inflation growth. The Brazilian government subsidized the enlargement of sugar cane production and the industrial capacity to process and transform ethanol (Brasil 1974).

The *Proalcool* had three phases. In the initial phase, ethanol was blended with gasoline in a 20% to 25 % proposition and a few distilleries participated. In July 1979, after the second oil crises and positive feedback from the press, the government decided to provide larger support to the program. The second phase consisted of E100 vehicles. In order to do so, the government involved local automobiles producers, which were mainly represented by Ford, General Motors, Volkswagen and Fiat, in the development of the necessary engine modifications to adapt the internal combustion engine. A specific line of credit was implemented to do so. Fiat was the first automaker to launch a vehicle that would run on 100% ethanol – The FIAT 147. Other models were soon launched including the Volkswagen Beetle, the Volkswagen Gol, the Chevrolet Chevette and the Ford Escort. The combination of governmental subsidies, high international oil prices and the new locally produced vehicles constituted the perfect ambience to make ethanol a great commercial success. In 1984, 94.4 % of new vehicles sold in Brazil would run solely on ethanol. At that point in time, the program had been considered by the government as a great achievement (Pamplona 1986).

In the last phase of the *proalcool*, the governmental subsidies began to decrease. By 1986 oil prices had fallen and in 1989 there was ethanol shortage, as sugar cane producers prefered to produce sugar instead of ethanol. In 1998 the subsidies were finally eliminated totally as the market could function freely. A recent introduction of the Flexi-fuel technology provided further stimulus for the ethanol producers in the country. The technology allows the vehicle to run on ethanol, gasoline or any mixture of both. The engine is equipped with a system that is able to analyze the fuel blend and control the fuel injection system and adapt all the different settings to optimize performance. The initial developments took place in the Brazilian branch of Bosh group in 1994. But it was not until 1999 that Magnete Marelli announced the development of the new type of engine with the appropriate software. The system was them launched to the public in 2003. In 2005, more than 75% of the new vehicles sold in Brazil were Flex-fuel (Anfavea 2006). Additionally, some models are also supplied with the LPG system, which can provide an economically feasible solution for fleet vehicles and taxis.

In the aftermath of the governmental intervention, it became clear that the economic viability of the ethanol *vis-à-vis* petrol depends on several external variables. However, the calculation of the net benefit to the country is not a trivial one. Some of the costs which include not only direct financial expenses but also environmental costs have not been completely assessed. There was a vast amount of negative environmental externalities related to the sugar cane production, which was gradually minimised by the ministry of agriculture and the ministry of the environment. On the other hand, the benefits include inflation control, creation of wealth and labour in poor areas and the fact that biofuels are in essence carbon neutral (Zapata 2007). From the innovation point of view, despite of the fact that a large amount of research was necessary to initially adapt the internal combustion engine to ethanol, very little modifications were actually needed to adapt the system especially from the second phase of the *Proalcool*. The same rational can be applied to the development of the flex-fuel system.

4.2 Hybrids – The Toyota experience with the Prius.

The story of how the Prius has been created can provide valuable insights into the nature of the hybrid technology, safely attaching it to the incremental innovation characteristics previously discussed. The Toyota Prius has represented a tremendous success for Toyota Motor Company as the first large scale hybrid (petrol-electric) vehicle to be supplied to the global market. Regardless of the fact that the Prius only represents a very small percentage of Toyota's global sales, it constitutes a great technological development, in terms of fuel consumption which directly affects CO2 emissions, and a fantastic marketing opportunity to show case an innovative product. For a company that had been regarded in the past as a follower, this pioneering experience not only projects its image of environmental conscious firm but also as a technological leader in the global market.

The Toyota Prius is unmistakably a progress from the single internal gasoline combustion engine as it is equipped with a traditional petrol fuelled engine and an electric motor. Toyota developed a system called *The Hybrid Synergy Drive System* that automatically switches between the electric motor and the internal combustion engine depending on the power needed to move the vehicle. The intuition is to rely less on the petrol fuel engine at low speeds and use its full capacity when more power is needed. The system allows the vehicle to have very low consumption when compared to standard vehicles of the same size (Toyota 2006).

The origin of the Prius can be traced to an internal committee created by Toyota Motor Company to forecast the future perspectives in the automotive industry for the 21st century– G21. It was established in September 1993, as a response for not having been invited to participate in The Partnership for the Next Generation of Vehicles (PNGV), created by the Clinton administration in the early 1990's. The committee's organized a project with the guidelines to develop an extremely economical mid-sized family car based on new production methods. The initial goal was set at 47.5 miles per gallon for the internal combustion engine. In the fist stages of the project, engineers believed that solely developing the internal combustion engine would bring about the necessary fuel economy. But in due course, it became clear that additional measures had to be taken in order to reach the proposed targets. The group decided to attach an electrical engine to the petrol-fuel one. For the 1995 Tokyo Motor Show, Toyota prepared a concept car with the system, presenting it as the Toyota's vision of the future (Taylor 2006).

The feedback the company received in the Motor Show was critical for the decision to produce the hybrid vehicle. Regardless of the fact that the system would add additional costs to the car, Toyota calculated that a vehicle, based on the concept car, could go into production if the fuel economy was enough to compensate for the additional fee and complexity added with the addition of an electric engine. Also it was clear that further development in the battery technology could be achieved. The technological advancement of the internal combustion has reached an inflexibility point but battery powered electric engines/batteries was something novel with great development potential (Taylor 2006). If the economics and the technological aspects were sorted out, the

timing for the project was ideal as there were plenty of environmental arguments to support the vehicle. The Californian market presented the desired environment to launch this type of vehicle as there was growing pressure from the California Air Resources Board.
The Prius was officially launched in Japan in October 1997 and sales began in December. During the first two years the generation I Prius was only sold in Japan. These initial years were necessary to carry out further development in the hybrid system and in the batteries. When the company developed the generation II model, global sales started. The Global market started to receive the first models in 2000. The success of the vehicle was staggering especially in Japan and the North American market. More advancements were gained from the batteries that became smaller and lighter, and the vehicle more powerful. At the present time, the Prius is in its third generation. The vehicle has experienced an increase in power from both the internal petrol fuelled engine and the electrical engine. It is equipped with a traditional DOHC 16 valve 1.5 litre petrol engine that produces the maximum output of 76 bhp and an electric motor that can produce 67 bhp. It also has a nickel-metal hydride battery that has a 201.6 nominal voltage. The vehicle has a (g/km) 104 emissions on a combined cycle and the fuel consumption of 65.7 litres/100km) (Toyota 2005).Table 2 presents the developments in battery electric in each of the three Prius generations.

Table 4.2 – The Generations of the Toyota Prius.

Prius Type	Generation I	Generation II	Generation III
Year	1997-1999	2000- 2003	2003-2006
Petrol Engine (HP)	58	70	76
Electric motor (Hp)	40	44	67
Acceleration 0-96 kph (seconds)	14.1	12.5	10.1
Battery-Pack Energy (W/kg)	600	900	1250
Battery-Pack Weight (kg)	57	52	45

4.3 Hydrogen Fuel Cells.

Hydrogen fuel cell cars are regarded by many as the answer to all our environmental concerns, but all we have seen so far are a few prototypes and a few buses. The achievements of the fuel cell industry – Ballard in particular – have been impressive; the ratio of Kw/$ has improved dramatically over the past fifteen years or so (Koppel 1999). In fact, in some respects the fuel cell car is competitive with the internal combustion engine car even today. So where are the problems? These appear to be in three areas: vehicle integration, manufacturability and infrastructure (cf. Nieuwenhuis and Wells, 2003, 72ff, Vergragt 2006, and Van den Hoed & Vergragt 2006).

Fuel cell vehicles have come a long way. Not too many years ago, a panel van was the smallest possible fuel cell vehicle, as the system took up so much space. During the 1990s we saw a rapid reduction in size and today's experimental fuel cell vehicles look, in terms of packaging and presentation, uncannily like conventional internal combustion powered vehicles. This is an area that does not in itself cause disruptive change as it captures skills and investments largely already in place. The real issues are elsewhere.

Most current automotive fuel cells run on pure hydrogen. This is a substance that does not occur in this form on our planet. On earth it only occurs bound with oxygen in the form of water, or bound with carbon in a range of hydrocarbons. In each case some process is needed to separate the hydrogen from these other elements and this requires energy, in some cases a large amount of energy, such that the total lifecycle impact of hydrogen does not always make it the most environmentally optimal fuel, except in places like Iceland (Nieuwenhuis 2005c). On-board reforming of hydrogen from hydrocarbon fuels such as methanol or even petrol has also been suggested. This would obviously add weight and complexity to the vehicle and would also use energy. It would however remove the need for large hydrogen production facilities and for a hydrogen distribution infrastructure. Recent experiments with compressed hydrogen have at least shown that by using very high pressures a sufficient amount of fuel can be carried in a car to give it an acceptable range of around 300 miles. This has also been an issue that has been causing concern over the years. This does show that the industry is achieving improvements in the move towards practical fuel cell cars at a steady rate. If this continues, we are certainly likely to see practical hydrogen fuel cell vehicles within the next five years or so and certainly by the much forecast 2012-2015 period.

In terms of manufacturability, Ballard is now in the early phases of setting up a manufacturing process for automotive fuel cells. This envisages a gradual, incremental increase in annual production to reach a peak of around 500,000 a year by about 2012-2015 in a single factory. So, if all goes according to plan, Ballard will be able to produce some half a million automotive fuel cell stacks each year. If we assume that the Japanese – led by Toyota – add a similar annual number, we have an annual production capacity of automotive fuel cells of around one million by 2015 (Nieuwenhuis 2005a). This means that the ability to build future fuel cell power units rests with a few companies, unlike today's IC engines, where every car maker has expertise. Thus not only will car makers be forced to outsource what they now do themselves, they will also lose one area of differentiation in the market. However, they will have some time to adjust to this new situation.

The total number of vehicles produced worldwide today is around sixty million. It is safe to assume that with China, India, Indonesia and others all in the fray by 2015, this number will have grown to nearer eighty million, if not more. The market share of newly registered fuel cell vehicles by then will therefore be a maximum of one eightieth of the global market. Given their business priorities, neither the Canadians at Ballard, nor the Japanese are likely to dramatically increase fuel cell production capacity before there is a clear sign of demand. Once this is apparent – if indeed it materialises – the lead time for another half million capacity facility will be at least a year, if not more.

Let us assume therefore, that by 2020 we will have a global automotive fuel cell production capacity of four million stacks. If we keep to our global vehicle production figure of eighty million by then we find that five percent of vehicles made can be fitted with a fuel cell. That is one in twenty. At this rate it will obviously take a while to have the majority of the park running on fuel cells. In practice, these fuel cell vehicles would probably not be equally distributed among world markets. Instead there are likely to be pockets of higher fuel cell car densities. One can imagine areas such as the state of California, Iceland, and the Canadian province of British Columbia – home of Ballard – enjoying a significantly higher density than Texas, or Romania, for example.

Much has also been made of the need to replace or replicate the existing fuel supply infrastructure with a hydrogen version. The building of a dedicated infrastructure is very expensive; it has been estimated at $5000 per car by Keith and Ferrell (2003). There is also a chicken-and-egg situation in that few fuel cell vehicles would be sold without a fuelling infrastructure, while no commercial organisation would build an infrastructure without some guarantee of demand.

With only five percent of new car sales being hydrogen powered, this is indeed difficult to justify. However, in British Columbia, California, Iceland and even South Wales (Nieuwenhuis 2005b, 2005c) there have been proposals for 'hydrogen highways' – corridors where hydrogen availability would be guaranteed at regular intervals. Clearly some government support would be required to encourage such a development and in California governor Schwarzenegger himself has been a keen supporter of this concept.

Obstacles to the introduction of hydrogen fuel cell vehicles are one by one being dismantled by technological and conceptual solutions. If this trend continues, we can have commercial fuel cell cars appearing on the roads of at least some parts of the world in the next decade. To that extent, Ogden et al. (2001) could be correct. They forecast an 'optimistic scenario' whereby 10,000 fuel cell cars would be produced between 2005 and 2008 and by 2010 this figure would be up to 300,000. One million a year would be reached before 2020 by which stage the technology would be cost competitive with conventional cars. Beyond 2020 10 new factories would be built each year.

At the same time, oil-derived fuels are likely to increase in cost. Supply of oil is now estimated to peak around 2010-15, while demand – from newly motorising nations such as China, India, Indonesia and Russia – will continue to increase. This could increase the demand for alternative powertrain technologies such as the hydrogen fuel cell. Alternatively, the car industry may decide – in a bid to preserve the tried and trusted internal combustion engine – to go for petrol- or diesel-hybrid solutions instead. Their fuels can also be derived from natural gas, coal or biomass even when oil itself became too costly. This perpetuation of internal combustion could well be used to postpone the inevitable moment when internal combustion will no longer be viable. In that case the hydrogen fuel cell could well continue to be the best future power train solution for several more decades.

5.Conclusion

The automotive industry is a fertile area for the discussion of the innovation theory. In this paper we have argued that the fundamental importance between radical and incremental innovation needs to be understood thought the lenses of the economics of the motor industry. The peculiar characteristics of the automotive industry must be fully comprehended and addressed in order to provide an ex-ante definition in several alternative technologies which include fuels and powertrains that try to break apart from the mainstream petrol-fuelled internal-combustion engine. In this sense, several incremental technologies have been discussed, especially ethanol powered vehicles and the hybrid technology. In the same way, the radical innovation that could be potentially disruptive hydrogen full cells has been analysed.

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