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Institutional, Technological and Commercial Innovations in the Brazilian Ethanol and Automotive Industry[1]

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> ‘Cicero demands of historians, first, that we tell true stories. I intend fully to perform my duty in this occasion, by giving you a homely piece of narrative economic history in which ‘one damn thing follows another ’. David (1985)

In Brazil, the most promising sources of renewable energy include ethanol and, more recently, biodiesel. Brazil has been producing ethanol for fuel since 1980, and the production of biodiesel began in 2003. Bio-fuels are expected to bring significant environmental, social and economic advantages as well as innovations like flex-fuel engines for cars and motorcycles. This chapter describes the institutional, technological and commercial aspects of Brazilian ethanol and automotive system innovations.

Demand for sustainable fuels has caused the rise of innovative organisations, the development of more efficient systems/technologies and commercialisation resulting in the diversification of supply sources, particularly with regard to environmentally friendly, clean and renewable energies. Several countries are seeking to reduce their dependence and use of petrol oil fuels, either by replacement with another source or another product or by adding other fuels that decrease pollution. We focus here on what has been the Brazilian approach to this sustainable strategy, describing how the associated innovation has spread throughout the automotive industry and the ethanol value chain and the roles of the governance structure and of the national innovation system in this transition.

This chapter is divided into five parts. Immediately after this brief introduction, the second section defines the concepts and describes the models that were used to analyse the Brazilian experience: the system of innovation, institutional and path dependence analysis. The third section describes innovation in the Brazilian automotive industry, whereas the fourth section addresses innovation with regard to the ethanol chain. Finally, the fifth section contains final remarks regarding the lessons that can be extracted from the Brazilian experience.

SYSTEM INNOVATION AND THE INSTITUTIONAL THEORETICAL APPROACHES

The fully matured economics of ethanol fuel in Brazil is a system innovation that has been conceptualized by Geels, Elzen and Green (2004) as the transition of a socio-technical system to another on the level of societal functions (for example, communications, or energy and transports in our case). The system innovation approach accounts for technological innovation, institutional change and the path-dependent sequence of events and, therefore, is a suitable approach for analysis. According to these authors, the system innovation can be characterised by four main features: a) supply-side and demand-side co-evolutionary development of technology, knowledge and industry structure; b) large-scale changes involving the structural elements of a societal socio-technical system; c) multi-actor processes involving a wide range of social groups; and d) a long timescale on the order of several decades. We may connect the Brazilian situation to these elements as follows:

- Ethanol leads to innovations in the agricultural, processing and automotive industries by providing a less expensive fuel to consumers;
- From the distribution system of the fuel, via petrol stations all over the country, to engine manufacturing, which involves a whole supply chain (even Mercosur-imported cars projected to run in Brazil have flex-fuel engines), the entire transportation socio-technical system has been affected; on the agribusiness side, sugarcane mills, which concentrate their production and research in southeast and northeast Brazil, have reached an economy of scale and spread the fuel technology to highly productive farms and ethanol production plants;
- The entire ethanol value chain is integrated and influenced by several social actors involving research support and sustainability programs, and;
- Ethanol production can be traced back to the 1930s when it was influenced by the progressive involvement of social actors and social change.

Using the system innovation as a framework, this report highlights some of the foundations of our analysis, specifically the institutional and path-dependence approaches.

An institutional, technological and commercial innovation in a production value chain concerns three main economic and political forces at different levels: the institutional environment and the organisations (macro level), markets (meso level) and the companies (micro level).

At the macro level, North (1990) defined institutions as the ‘rules of the game’ and organisations as ‘the players’. The oil crisis in the 1970s provided the institutional incentive for the Brazilian military government to start a program called PROALCOOL (‘*Pro-alcohol*’, see section “Innovation in Brazilian Ethanol Commercialisation”). The main goal of this program, which was supported by law and public investments, was to find alternatives to fossil fuels. Likewise, at the meso (market) and micro (company) levels, Williamson (1993) argues that the institutional environment provides fundamental rules (property rights and the law) that induce the formation of different types of organisations that, in turn, structure the institutional arrangement. With the incentives of PROALCOOL, several agricultural industries began to produce ethanol, and the automotive industry began to develop engines that could work exclusively with this new fuel.

Olson (1965) has defined an organisation as a group of individuals with common interests. Organisations develop collective actions that maximise the value of the founders and try to increase competitiveness. Brazilian examples of organisations in the ethanol value chain are UNICA[2] (for ethanol production) and ANFAVEA[3] (for car makers).

Public and private organisations also contribute to the competitiveness of the environment. With regard to innovation in ethanol production, there are both private research organisations like CTC[4]and public organisations like EMBRAPA[5]. Together, they could significantly change the standards that dictate competitive advantage in the market. In other words, changes in individual strategies can change the competitive environment of a market and, consequently, the institutional environment. How, exactly, the organisations interact is particularly important to the competitive dynamics (Olson, 1965), as further discussed in the section "Innovation in Brazilian Ethanol Commercialization".

The system innovation that resulted in a mature market economy of ethanol fuel involved several institutional changes. In this regard, Alston et al. (1996) have discussed two main forces that drive institutional change: (1) The symbiotic relationship between institutions and organisations that defines the structure of incentives (for example, in sugarcane production, the strong coordination led by the automotive industry and the vertical integration of the ethanol industry in sugarcane production made possible the intense symbiotic relationship in those chains); and (2) The feedback that drives the perception and the reactions of organisations to new opportunities (for example, in Brazil, government incentives, the right signalisation to the market and the reputation of PROALCOOL paved the way toward long-term investments in innovations).

This chapter focuses on three main institutional changes in the ethanol value chain: the rapid growth of the ethanol sugarcane industry, the emergence of the ethanol engine and its infrastructure and the flex-power technology.

Given that the sugarcane economy represents the first established non-extractive production mode in the country since the Portuguese arrived in the New World, it is clear that the influence of a path-dependent sequence of events determinates the adoption of this particular fuel solution. As David (1985) defined, '*a path-dependent sequence of economic changes is one of which important influences upon the eventual outcome can be exerted by remote events…*' (p. 332). These remote events include chance elements. David further emphasised that a path-dependent history is sometimes the only way we can understand the logic of a current state of things. Indeed, David's three-determinant elements for path dependence formation, *technical interrelatedness*, *economies of scale* and *quasi-irreversibility of investment,* seem to be the very pillars upon which system innovation takes place.

We have developed a model, based on similarities in the institutions, technological and commercial innovations in the Brazilian Ethanol Industry, which considers the evolution from technological innovation to market adoption with institutional changes governing the process. The model is summarised in Figure 9.1.

Figure 9.1

To describe the technological, commercial and institutional innovations for ethanol and the automotive industry we propose the following complementary model. The institutional and organisational environments depict how the changes provide a sustainable structure of governance at the macro level (Institutional Innovations). Also at the macro level, we incorporate the concept of path dependence as a longitudinal approach. In the meso and micro levels, we analyse which innovations (Technological Innovations) occur in each industry in the automotive (suppliers and makers) and ethanol (sugarcane and ethanol production) chains. We choose the main transaction in each chain (TA1, TA2, TE1 and TE2) to describe the commercial innovations (see sections "Innovation in Brazilian ethanol commercialisation" and "Commercial innovations in the Brazilian automotive sector"). Figure 9.2 further illustrates this model.

Figure 9.2.

The longitudinal analysis of the Brazilian system of innovation is discussed in the next section.

INNOVATION WITHIN THE ETHANOL CHAIN

The system innovation assumes the pre-existence of a governance structure involving several different agents (see Figure 9.2). The sugarcane and ethanol industry agents coordinated the knowledge, development and the flow at the agricultural sector, and then the information and skills spread throughout the automotive sector, reaching the flex-fuel technology. Both innovations are described below.

Path dependence and the innovation in the Brazilian sugarcane sector

The sugarcane plant (*saccharum officinarum*) was first found in India, from there it went to China and Persia (in the time of Alexander), and from there to Syria, Egypt and Sicily. The Portuguese *infante*[6] D. Henrique introduced it in the Madeira Islands during the fourteenth century, giving Portugal an important source of revenue during the subsequent centuries (Souto Maior, 1967).

The discovery by the Portuguese in 1500 immersed Brazil in the mercantilist economy, which involved Portuguese navigational expertise to promote intense commerce with India (mainly for specialties like sugar that sold for a good price in Europe). The first economic activity in Brazil involved the extraction of an ashy (*verzino* in Italian, *brésil* in French or *brasil* in Portuguese) wood used as the source for red colouring in fabrics; it was called '*pau-brasil*' (ashy wood) and gave the country its name. Sugarcane plantations were introduced between 1516 and 1525 in Brazil, constituting the first colonial productive activity. The production of sugarcane employed a technology already dominated by the Portuguese, namely the slave-operated central *engenho* (machinery that processed the sugarcane to produce sugar), located in the middle of the plantation. Therefore, sugar production was the first non-extractive activity in Brazil, and it provided Portugal with more wealth than all the other colonial activities together, including mining. By 1570, Brazil had approximately 60 *engenhos*, most of them in the Northeast part of the country. Between 1570 and 1710 Brazil exported an average of 28,000ton a year, reaching the peak of 58,800ton in 1600 (Vicentino and Dorigo, 1998).

In addition to the main *engenho* used for sugar production, a small *engenho* (or *engenhoca*) was used for sugarcane liquor production (*cachaça*), the first alcohol by-product of sugarcane production and an industry that was particularly important to the slavery trade in Africa.

By the end of the seventeenth century, competition from Central America and the West Indies caused sugar prices to drop to commodity levels, and the importance of Brazilian sugarcane production to the Portuguese economy decreased accordingly. Despite the competition and two major setbacks, the war against the Dutch settlements that destroyed many assets in the Northeast and the massive workforce transfer to gold mining, sugar production was never interrupted.

Institutional and technological innovation in Brazilian Ethanol production

Some important organisations with different origins were important to the governance structure of the Brazilian ethanol system of innovation. EMBRAPA and CTC are good examples. EMBRAPA is the federal and public agency of innovation for the agricultural sector. Individual specialised centres exist in almost every region of Brazil. The EMPRAPA Cenargem[7] has conducted research in the adaptation of agricultural species to different regions of the country and houses a genetic collection for use in developing genetically modified crops, including sugarcane. CTC is an example of private investments in agricultural innovation. Sustained by private companies, it supports research in cellulose, ethanol, biotechnology, agronomy, benchmarking, rural and industrial mechanisation, sugarcane and ethanol production and bioenergy.

The 1975 law (no. 75,593), from which the PROALCOOL program was initiated, established price guarantees to ethanol producers based on corresponding sugar prices. Several subsequent laws renewed the incentive until the ethanol market was established and de-regulated in 1999. On the consumer end, prices were guaranteed to be lower than petrol, a situation established by governmental subsidies when the production costs exceeded petrol production prices. The consumer prices were de-regulated in 1996, putting an end to this incentive (Puerto Rico, 2007). Today, ethanol production prices vary significantly depending on the producing region. Furthermore, they float according to international sugar prices, which compete for ethanol raw materials in a free market. Ethanol production has generally become less expensive than petrol in the south-southeast of the country (mainly São Paulo, which is the main consumption centre).

Currently in Brazil, 48% of the total energy generated comes from renewable sources, and sugarcane supplies 15% of the total country's domestic energy, mostly for automobile flex-fuel engines, (OECD, 2011). The country is not only the world's largest producer of sugarcane ethanol but has also become a leader in innovation technologies and processes for ethanol production. The state of São Paulo has the largest concentration of sugarcane ethanol production sites in the country.

In ethanol production, the governance structure has been based on a strong relationship between agriculture and industry, which has solved the problem of coordination and provided support for rapid growth in production scale. The sugarcane industry has used this economy of scale to invest in agricultural and industry innovations. Most of this innovation was driven not only by efficiency and/or productivity goals but also by sustainability concerns.

The agricultural or agronomic innovations that were conducted by the sugarcane industry and several research institutes and universities include direct seeding and rotations (with other cultures) every 4 years. This sustainable innovation helps maintain/conserve soil and the water quality. In addition, thanks to the introduction of mechanical engines, the crop-burning process used in human harvesting is no longer necessary.

Although some research associations are owned by ethanol organisations, the government itself still invests in promoting innovation, especially in the agricultural sector. UNICA, the largest private Brazilian association of ethanol producers, contributes significantly to the governance structure of the industry's innovation and supports communication and promotion of the product in other countries (UNICA, 2011).

The production of ethanol has also led to promising technological innovations. One of the newest developments in ethanol production is called second-generation ethanol. Because plant cells are surrounded by cellulose, a polymer that is very hard to penetrate, developing an economically viable means of breaking down the cellulose is essential to the production of second-generation ethanol, which can be extracted from any biomass (not just from sugarcane). Once implemented, this technology will increase bio-fuel production without requiring the extension of actual sugarcane plantations. Another example of technology that is being developed employs enzymes found in termite and ruminants digestive systems to decompose the cellulose. An alternative innovation involves the use of specific acids.

The commercial side of ethanol chain involves innovation challenges regarding price oscillations. The price of gasoline and the price of diesel are controlled by the government, which also, therefore, controls the percentage of ethanol mixed in the gasoline. Because the ethanol price is less controlled, it depends more on the law of supply and demand. For example, since early 2011, the State of São Paulo has witnessed a 19% increase in the price of ethanol. According to the National Agency of Petroleum, Natural Gas and Biofuels, ANP (ANP, 2011), the average price of a litre of ethanol fuel in this State has increased to R$ 1.99 (compared with R$ 1.67 in December 2010). For this reason, gasoline is currently more competitively priced than ethanol in 25 states and in the Federal District. Although showing an exceptional situation that tends to return to balance, this example reveals the nature of the price oscillations problem that needs to be addressed.

To reduce this problem, 30 sugar and ethanol plants, which are responsible for processing 65 million tons of cane (12% of the annual volume processed at the centre-south region of Brazil), attempted to anticipate the 2011/12 crop of sugarcane (UNICA, 2011). Given the high price of sugar in the international market, the industry has decided to produce sugar instead of ethanol. Another potential commercial innovation involves the future stock-exchange prices for ethanol. Between 7.1 million and 8.9 million tons of sugar that were produced in April 2011 are already price-fixed on the New York Stock Exchange.

The ethanol market is also dependent on other international institutional environments. For instance, the United States is attempting to counterbalance the growing economic power of China by clearing space for bio-fuel development and production. Another example is the current US tariff on ethanol imports, which could be reduced. In December 2010, though, the US Congress passed the renewal tariffs on ethanol import (AEB, 2011).

Innovation in Brazilian Ethanol commercialization

Brazil has mixed ethanol and petrol for fuel uses since the 1930s. Law 17.917 (of February, 20th, 1931) established the use of 5% of ethanol in all imported petrol. In 1948, law 25.174 extended the 5% mix to Brazilian-produced petrol. During WWII, the mixtures reached higher levels (Flores, 2010). Therefore, mixing alcohol with petrol has been an historical national solution to the international shortages in Brazil.

In 1973, the oil crisis hit the Brazilian economy, an economy that was already indebted and suffering from high inflation and a weak currency. At that time, Brazilian oil production was far below demand, forcing the country to rely on oil imports for consumption and growth. Table 9.1. contains the main figures pertaining to the Brazilian economy from 1972 to 1979, highlighting the large economic dependence on oil imports.

Table 9.1.

The Brazilian growth strategy was based on accruing external debt as a way of capitalising the economy, increasing international reserves and financing external trade imbalances. However, the relative weight of oil (to total) imports was rising with the devaluation of Brazilian currency, the rise of international oil prices and the Brazilian economy growth itself, which demanded more oil consumption. Furthermore, because it was a truly global oil crisis, external markets were not suitable to the Brazilian export growth. Though the devaluation of currency fostered exports, it did so at the expense of imports. The bottom line was that the oil share reached more than one-third of the total imports in 1979.

The military government put forward the traditional idea of substituting petrol consumption with ethanol, instigating the PROALCOOL program. The program was officially announced by President Ernesto Geisel in his televised speech on October 9th, 1975 (Geisel, 1976) and sanctioned by law 76.593 on November 14th, 1975. From 1975 to 1979, the program consisted of fostering ethanol production for fuel mixtures, the traditional Brazilian response to petrol supply crises. The PROALCOOL program first aimed to drive the production of dehydrated ethanol (99.5% pure ethanol), adding it to petrol at a rate that would not require engine modifications (a proportion between 10% and 15% or E10 and E15, respectively). Later research showed that the ethanol content could reach up to 25% and still require only minor engine adaptations. The resulting fuel is technically termed *gasohol*. This approach remains in effect today; Brazilian petrol has been 25%

ethanol (E25) since 2007; the actual proportion may vary slightly according to the ethanol supply.

In 1978, on the verge of petrol rationing that would decelerate Brazil's expensive economic growth, automotive industry representatives leaded a national agreement and produced 250,000 vehicles exclusively propelled by ethanol in 1980, 300,000 in 1981 and 350,000 in 1982, and agribusiness producers produced enough ethanol to power the new fleet, in exchange for the governmental promise not to put the rationing in effect. The protocol was signed on September 19th, 1979, and successfully halted the petrol rationing movement (Garnero, 1980). Part of the deal involved a governmental tax incentive for cars powered by the new engine, resulting in 5% less in the IPI, the Tax over Industrial Products (Puerto Rico, 2007). Product distribution across Brazil's 8,500,000 square kilometres was delegated to Petrobras, the Brazilian state petrol company that enjoyed a petrol *distribution* monopoly at that time (though retail was free marketed). That solved the distribution problem, but, at the retail level, there was another one: how to immediately store and sell ethanol in every petrol station in the country? The creative idea was to abandon the commercialisation of premium ('blue') petrol and to keep only the regular ('yellow') petrol at the pumps, using the retail premium petrol tanks to store ethanol. By this means, every Brazilian petrol station could almost instantaneously commercialise the new fuel because every petrol station would have at least a petrol pump and an ethanol pump.

The consumer price of ethanol was determined by the producers' value plus the distribution cost. With this price strategy, the final cost of ethanol was higher than petrol's. To compensate, the government fixed the final ethanol price in 65% of petrol's (consumption of ethanol engine was 20% higher than regular petrol engine). During the Iran War in 1982, the Brazilian government fixed the ethanol price in 59% of petrol’s to provide incentive for ethanol consumption (Puerto Rico, 2007: p. 75).

These developments led to the interaction between the two organisations/areas, namely automobile manufacturing and the sugarcane agribusiness.

INNOVATION IN THE AUTOMOTIVE CHAIN

This section explores the same innovations and path dependence (as above) in the automotive chain, in which the two main innovations were the creation of the ethanol car and the flex-fuel engine.

Path dependence in the automotive chain

The automotive industry was one of the first industries to internationalise and arrived in Brazil early in its internationalisation process. Ford entered the market in 1919, followed by GM (General Motors) in 1925. It was difficult for Brazil, a late bloomer in industrialisation, to afford the automotive industry, as evidenced by the fact that gasohol had been a means of saving foreign currency since the 1930s. After WWII, the automobile industry was chosen as the leading industrialisation sector by President Juscelino Kubitscheck, who put forward the GEIA (Automobile Industry Executive Group), a governmental committee gathered to recommend policies to attract other foreign automakers to Brazil, while committing them contractually to gradually enhance local content. The first automobile multinational to accept the Brazilian government’s invitation was the German Volkswagen (VW), who commenced local production in 1953; Fiat followed in 1974.

A growing automobile industrialisation process requires that the main transportation system is the road. Consequently, to transport people and goods throughout Brazilian's 8.5 million square kilometres, Brazilians have become fuel dependent. Therefore, when the country was hit by the international oil crisis, it was the very industrialisation of the country and its required mode of transport that pushed Brazil toward an alternative to imported oil.

Institutional and technological innovation in the automotive industry

Ethanol-engine technology has been made possible through long-term research projects at CTA, in Sao Jose dos Campos, Sao Paulo. Established in 1947, CTA has had a crucial role in the development of Brazilian gasohol and aerospace programs, giving birth not only to the ethanol engine but also to EMBRAER, a world-class airplane manufacturer (which was later privatised). According to Dahlman and Frischtak (1993), of the dozens of Brazilian military technical institutes that were built in this period, CTA was the most important. Urbano E. Stumpf, engineer at CTA, furthered the work of Eduardo Sabino de Oliveira and Lauro de Barros Siciliano to develop the first Brazilian modern prototypes of ethanol-powered engines in the automotive industry (Teixeira, 2005).

Private companies also played important roles in the innovation process. The first exclusively ethanol-powered passenger car produced in Brazil was a 147 modified model from Fiat in 1978. As discussed in the section '*Innovation in Brazilian ethanol commercialisation'* a protocol signed in the same year by President Figueiredo and automotive industry representatives (mainly ANFAVEA) invited all the other automakers into the program.

Also, in conjunction with governmental and independent research institutes and universities, multinational corporations established engineering centres in its Brazilian subsidiaries, pushed by the availability of well-trained engineers with comparatively less expensive labour costs and the local market characteristics (Amatucci and Bernardes, 2007 and 2009; Balcet and Consoni, 2007; Consoni and Quadros, 2006; Dias and Salerno, 2004; Quadros and Consoni, 2009; Queiroz and Carvalho, 2005). This is particularly the case in the automobile business. According to Amatucci and Bernardes (2009), product development in Brazilian subsidiaries of international automakers resulted from the need to locally adapt the product, the presence of a Porter's diamond in the local industry, availability of a specialised workforce and the investment of headquarters in training, expatriation and use of standardised product development software. Not only did the main automakers such as GM, Fiat, VW, Ford and Renault support local product development capabilities, but Brazilian subsidiaries of auto-parts suppliers did so as well (take, for instance, the cases of Robert Bosch, Magneti Marelli, Delphi and many others). Indeed, Magneti Marelli's product development capabilities in Brazil were responsible for the important development of the second-generation flex-fuel technology (based on software).

In addition to technological innovations in both public and private organisations, institutional changes in the economic and political environments pushed the automobile market, as a whole, to adopt the flex-fuel technology. By adopting this technology, Brazilian consumers could choose their fuel combination (petrol and ethanol) depending on their own value perceptions (Amatucci and Spers, 2010). Analysis of the flex-fuel engine technology adopted by Brazilian automakers reveals parallels between this process and the US experience.

In the US, automakers have been developing electronic fuel injection for use with vegetable-sourced fuels since the middle 1980s, a persistent reflection of the petrol crisis of the 1970s (Teixeira, 2005; Yu et al, 2009). Via the Alternative Motor Fuels Act of 1988, the California Air Resources Board regulated technical parameters for a dual-fuel engine and offered tax incentives to support its adoption, and the Clean Air Act Amendments from 1990 nationally attributed to EPA (US Environment Protection Agency) powers to control emissions. Under this governance structure, the auto industry offered the ethanol engine alternative to consumers in California. From 1992 to 2005, approximately 2.5 million such cars were sold in US, despite the fact that there was not enough ethanol to fuel them all (Teixeira, 2005).

Early bi-fuel technology, used in US, was developed by Robert Bosch, and relied on a dielectric sensor in the fuel feeding line, which took advantage of the dielectrical differences of the two fuels to provide the proper adjustments to the burning parameters. This ‘first generation’ bi-fuel technology (called ‘bi-fuel’ instead of ‘flex-fuel’ because it does not allow mixing of the two fuels but works with only one at a time) added costs to the regular electronic injection command device, and it was well adapted to the specific US anhydrite ethanol.

In Brazil, early ethanol research also began as an answer to the petrol crisis of the 1970s. However, before electronic injection was available, the auto industry worked with two different engines, a regular petrol engine and an ethanol only engine. This double standard shortened scale efficiency, as the physical characteristics of ethanol demanded several engine modifications, such as corrosion-resistant materials, as well as different regulations and compression rates. Thus, the differences between the two engines were considerable, demanding different production lines.

According to Yu et al. (2009), the flex-fuel innovation in Brazil was born atop previous technological development, mainly electronic injection and its application to ethanol engines. Despite the efforts of the technology supplier to persuade the Brazilian automakers, adoption of the Robert Bosch technology used in US did not happen in Brazil. For the Brazilian market, the additional costs associated with the dielectric sensor prevented the automakers from buying the innovation.

It was the Brazilian subsidiary of Magneti Marelli that introduced the 'second generation' of flex-fuel technology, or the SFS (*Software Fuel Sensor*). The new technology works on a feedback basis, processing information about burned gases (from the escape system) that is already collected via the regular electronic injection system. The SFS system is completely software based and for all practical effects, apart from the fact that the electronic module processor had to be upgraded to receive some 100.000 new code lines, it has no marginal costs if compared with the traditional injection controller. Therefore, once the R&D is amortised, each additional device adds no extra costs to the engine.

That was not enough for the industry to adopt the new technology, though. At first, the automakers were not very enthusiastic about this new technology either. The innovations were presented to the major Brazilian sectors of the global automakers, but it took some time for the market to evolve to the new technology. Apparently, the automakers and their consumers were still resentful about their past experiences regarding pure alcohol engines (for which sales relied on governmental tax incentives but which suffered from ethanol supply shortages) caused by the technical and economic problems of the incipient development of the ethanol industry.

Adoption of the new technology was delayed until an event at IPT, where Bosch and Magneti Marelli had the opportunity to present their technology to representatives of the industry and of Brazilian government representatives that the situation was changed. With IPT entering the game, the new governance structure of innovation received government attention, and the incentives provided to pure-ethanol engines were extended to (future) flex-fuel engines. That was not a small step, once this technology allows the customers to use petrol or ethanol, and therefore the environmental gains from the subsidies are not granted. It was only then that the automakers fully adopted the innovation.

Thus, evidence suggests that the early process in California and the more recent development in Brazil had followed the same pattern. The Robert Bosch bi-fuel technology of the 1980s, did not take off until the State of California and US federal incentives were put in effect. Only then the American auto industry adopted the innovation, leading to the sale of an impressive number of bi-fuel engines in the American market even when there was not enough ethanol available for all of these cars.

Likewise, it took the Brazilian government's extension of tax incentives for pure alcohol engines to the new flex-fuel technology to get the industry on its way. The first to adopt the Magneti-Marelli innovation in Brazil was Brazilian VW with its Gol Power 1.6 Total Flex, in 2003.

Another parallel can be traced regarding the technological innovation development and its availability, before its adoption. During the technological development phase, suppliers in both cases had worked alone without support from industry or the government. In Brazil, the Brazilian sections of Bosch (since 1988) and Magneti Marelli (since the middle 1990s) developed prototypes of the flex-fuel, lowering costs related to the expensive sensor that had been necessary to balance the fuel mixture. With this kind of governance structure, the lack of support was so dramatic that the suppliers had to buy their cars in the market to develop and test the prototypes. Some technicians tested the new devices in their own cars.

In Brazil, it followed that the new technology attracted new players both in the supply industry and among the automakers themselves (for example, GM preferred an in-house solution to provide their own flex-fuel devices). Therefore, the flex-fuel technology market is virtually the pure competitive market from textbooks. With competition and scale, the new technology gained market operational conditions, such that the Brazilian government eventually dropped the incentives on flex-fuel vehicles in 2010. Furthermore, the Brazilian flex-fuel fleet grew exponentially, as shown in Figure 9.3.

Figure 9.3

Commercial innovations in the Brazilian automotive sector

The production of ethanol-only powered vehicles reached its peak in the middle of the 1980s, when more than 90% of passenger-car production focused on ethanol-powered engines. In 1989, however, ethanol demand surpassed its supply, causing shortages. Long lines appeared at petrol stations, causing mass consumer abandonment. This history continues to influence consumer behaviour even today. Eventually, international oil prices dropped to 'normal' levels, eliminating the economic advantages of ethanol.

As a result, sales of new ethanol cars dropped to 4% in 1994 and 0.56% in 1996. Some small shops offered 're-converting' services to turn ethanol engines 'back'to petrol engines during this period. These macroeconomic factors, allied with technical issues characteristic of innovative processes (weaker performance compared to traditional engines, lower efficiency, difficulties with cold starts, corrosion problems and so on), caused consumers to view ethanol engines as inferior (Kremer and Fachetti, 2000).

Even years later, with a reliable ethanol supply and fully developed technology (enhanced kilometres per gallon, although still 30% less efficient than today's petrol engines, and delivering more horsepower than an equivalent petrol engine), the market remained hesitant to adopt the exclusively ethanol-powered engines.

Ethanol-only cars gradually lost value in the secondary market (used cars), costing less than their petrol peers, and they practically disappeared from assembly lines.

The flex-fuel technology eliminated the market's fears about fuel shortages and the inconveniences of international oil price fluctuations. The VW Gol 1.6 litre, powered with injection technology from Magneti Marelli, the first hybrid produced in large scale in Brazil, was rapidly imitated by other players (Mello et al., 2005). The latest figures from March 2009 indicate that 87% of all new vehicle number plates are registered to cars with flex engines (Automotive Business, 2009).

This new technology changed the process of choosing between ethanol and petrol. Before the flex-fuel engine, which type of car to buy was a one-time and long-term decision; now, the decision is which fuel to use -- a daily and non-durable decision that carries no consequence in terms of vehicle depreciation or resale pricing. It is purely a matter of immediate price and sustainability.

As the flex-fuel technology has provided scale gains both to the industry and to suppliers, the incentives have become unnecessary and, consequently have been eliminated in 2010. However, the Brazilian government continues to use tax incentives as a means of market intervention, and the ethanol market is subject to strong economical oscillations. Therefore, it would not be surprising if the incentives return.

FINAL REMARKS

This brief historic report on the Brazilian ethanol experience, from its production as fuel to mix with petrol to the flex-fuel technology, brings to light a system innovation or social function transition that can be broken into three parts: the ethanol production increase to meet PROALCOOL goals of gasohol availability;

the pure ethanol and the pure ethanol engine adoption by both the industry and the market (included in this phase is the distribution problem solving); and, after the decline of phase II, a third phase consisting of flex-fuel technology adoption. These three phases are further summarised below.

Phase I: Gasohol (EX8)

Each phase influenced the following phase, and the first phase was strongly path dependent on the Brazilian history of sugarcane plantations and previous ethanol-petrol mixtures as a way to save foreign currency. This solution, well known to the Brazilian economy, has been ‘recycled’ to respond to the international oil crisis of the 1970s (so that, in this latter case, although important to the systemic transformation, the first phase was not really an innovation (unless regarding the perfection of the mixture and ethanol quality) in the technological sense or in the social sense.

Phase II: Pure Ethanol Engines

The second phase (and beyond), even with the inheritance of the first phase and all prior Brazilian history, had both technological and social innovations that involved rule, private companies and other social entities, such as class associations, being widely adopted by Brazilian consumers. The solution faded out due to offer fluctuations that severely penalized the locked-in pure ethanol engine owner.

Phase III and beyond: Flex-fuel

The third phase also brought technological innovation and social mobilisation in order to bring commercial viability. With the flex-fuel car, the consumer could choose the best fuel with regard to price and sustainability. This flexibility has ‘unlocked’ consumers to better face supply oscillations. With the Brazilian economic growth of the 2000s, which brought a large portion of formerly excluded population into the market, a record number of cars were sold. In addition to this economic growth, the price of sugar was also attractive. Investments were and are necessary to follow this internal market-consumption increase and the external demand for sustainable fuels. The Brazilian system of innovation still provides incentives for the innovation. Some future examples are: cellulose ethanol, ethanol for aircrafts, diesel from ethanol, ethanol lubricants, genetically modified sugarcane plants, and new sources of ethanol, among others. The automotive industry is also investing in improving the efficiency of the flex-fuel engines.

Four common elements

All three phases have some common elements without which each phase would not exist. First is the strong perception of a social problem that must urgently be solved, i.e., a vision that things just cannot go on the way they have been. Second is the availability of a technology, which, when socially combined with logistics solutions (in other words, when put in motion), can make the social solution viable. It seems that the technology is often available beforehand; the difficult part is to put it in motion. The third common element is that the social arrangement (to put the technology in motion to address the perceived problem) needs to be catalysed by the action of one or more entrepreneurs. By the same token, governmental incentives are necessary in the early stages of the transition; however, they can be withdrawn when scale, productivity and consumer confidence achieve normal market conditions.

An essential part of the social transition is market adoption of the new technology. A fourth common element to all the above phases is the initial fragility of the situation, which requires that the customer walk an extra mile, paying a higher price while tolerating an inferior performance, until the technology is perfected. Table 9.2. illustrates all the phases that were supported by entrepreneurship pushing institutional change. Future commercial innovations demand supranational organisations and an institutional environment that support global ethanol consumption: for instance, an initiative to foster Africa's sugarcane economy to provide an additional ethanol source.

Table 9.2.

In conclusion, the institutional changes regarding ethanol fuel in Brazil provide a stable governance structure to mediate the development of all phases of the production chain from sugarcane to the automobile; and economic agents such as UNICA and the Brazilian government are striving for international institutional changes to extend the local production chain to a global one.

NOTES

1. We want to express our gratitude for the information provided by PD executives from Bosch and from Magneti Marelli, respectively the first generation (hardware-based) and the second generation (software-based) flex-fuel technology pioneer providers; for the information provided by two executives from FTP (Fiat Powertrain), flex-fuel technology adopters and ethanol engine pioneers; and the assistance provided by a former ANFAVEA and Brazilian VW president, the social entrepreneur who strongly influenced the adoption of ethanol as fuel in the Brazilian auto market and who served as the ethanol retail distribution idealizer.
2. União da Indústria de Cana-de-Acúcar (Sugarcane and Ethanol Industry Union) For more information about UNICA visit: http://english.unica.com.br/
3. Associação Nacional dos Fabricantes de Veículos Automotores (Automakers National Association) - For more information about ANFAVEA visit: http://www.anfavea.com.br/index.html .
4. Centro de Tecnologia Canavieira (Sugarcane Technology Center) - For more information about CTC visit: http://www.ctcanavieira.com.br/site/index.php
5. Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agriculture Research Organisation) - Further described in the section "Institutional and technological innovation in Brazilian ethanol production". For more information about EMBRAPA visit: http://www.embrapa.br/english .
6. *Infante* was the Portuguese or Spanish legitimate son of a King who was not inheritor of the throne.
7. For more information about EMBRAPA Cenargem (Genetic Resources and Biotechnology Centre for Plants), visit www.cenargen.embrapa.br

8. EX = different proportions of ethanol in gasohol: E5, E10, E25 and so on.

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Figures

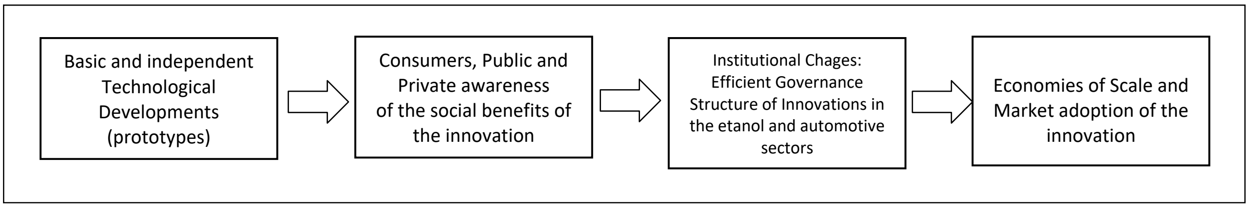

Figure 9.1 Institutional changes and governance structure mediating the market adoption of a technological innovation

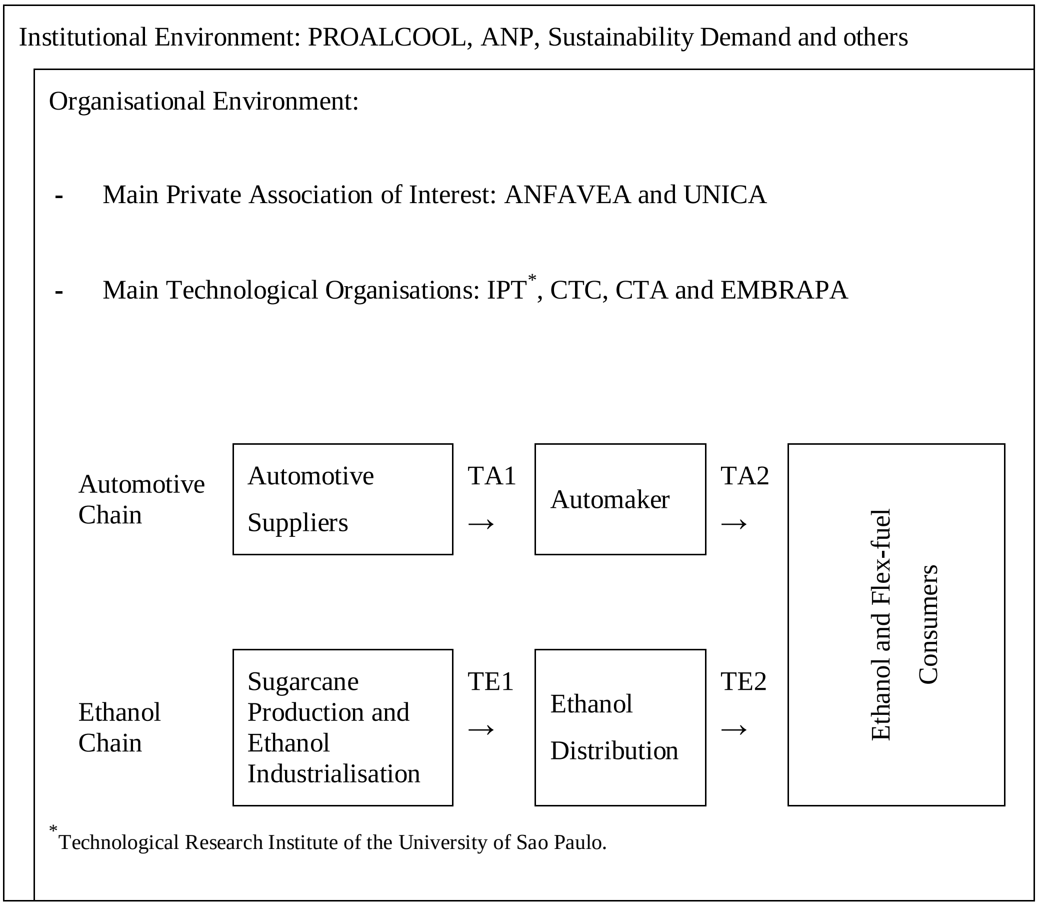

Figure 9.2 Brazilian Ethanol and Automotive Innovation System

Notes: TA1: Transaction between Automotive Suppliers and Automakers

TA2: Transaction between Automaker and the Consumer

TE1: Transaction between Ethanol Industrialisation and Ethanol Distribution

TE2: Transaction between Ethanol Distribution and the Consumer

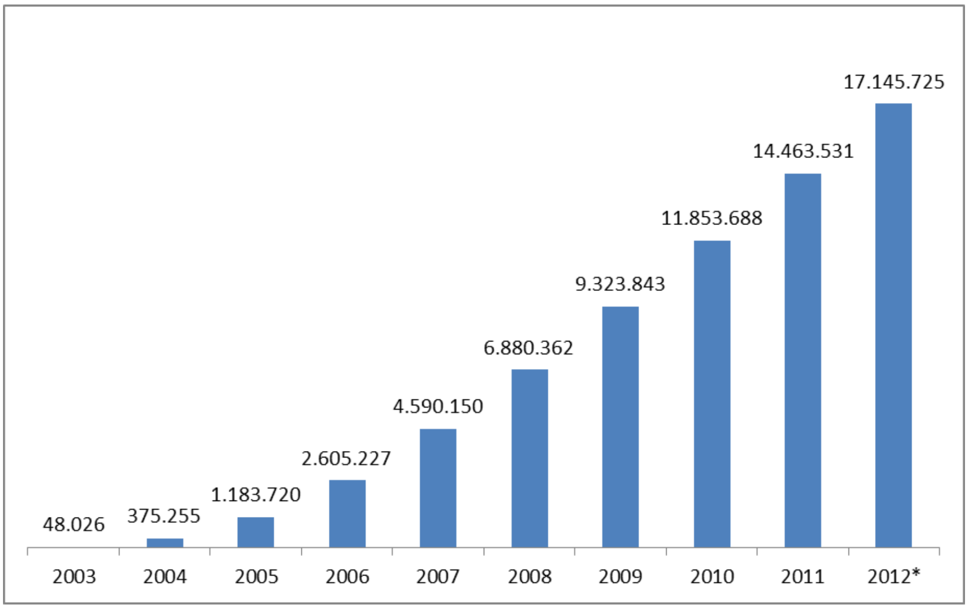

Figure 9.3 Brazilian flex-fuel fleet evolution: cars and light trucks

Note: *2012 - projected.

Source: MMA (2011).

Tables

Table 9.1 Brazilian Economic Growth, evolution of External Debt and the importance of

Year	*GDP (3)*	*Annual growth (3)*	*Gross ext debt (1)*	*Liquid ext debt (1)*	*Exports (2)*	*Imports (2)*	*Oil Imports (2)*	*% oil/imp (4)*
1972	58,539	12%	9,500	5,300	3,991	4,232	469	11.1%
1973	79,279	14%	12,600	6,200	6,199	6,192	769	12.4%
1974	105,136	9%	17,200	11,900	7,591	12,641	2,961	23.4%
1975	123,709	5%	21,200	17,200	8,669	12,210	3,100	25.4%
1976	152,678	10%	26,000	19,400	10,128	12,346	3,354	27.2%
1977	176,171	5%	32,000	24,700	12,139	11,999	3,660	30.5%
1978	200,801	3%	43,500	31,600	12,658	13,683	4,093	29.9%
1979	224,969	7%	49,900	40,200	15,244	17,961	6,188	34.5%

Note: US $ 1,000,000

Sources:(1) Adapted from Banco do Brasil and Banco Central apud Lacerda et al., 2000:114
(2) Adapted from Garnero, 1980:28
(3) Authors with data of World Bank
(4) Oil imports over exterior trade balance

Table 9.2 Phases of the Ethanol and Automotive System of Innovation

Innovation	*Phase I: Gasohol (ex)*	*Phase II: pure ethanol engines*	*Phase III: flex-fuel*	*Future*
Commercial	Creativity to solve logistic problems	Economy of scale provided by sugarcane plantations.	Competition with sugar and energy	Access to global market
Technological	Ethanol Engine Prototypes (FIAT/CTA)	The 'Alcohol Car' and the agribusiness technology	The 'Flex-fuel' car	Ethanol from cellulose
Institutional	Oil Crisis and Import/Export unbalance. PROALCOOL program	Tax incentives	Sustainable demands	Supra-national institutions

Source: Authors