THE ECONOMICS OF ETHANOL PRODUCTION IN BRAZIL: 
A PATH DEPENDENCE APPROACH

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Abstract: This study aims to analyze the relationship of path dependence in economic and institutional system of ethanol in Brazil. As a result, the ethanol, after stages of growth and challenges, has become part of the Brazilian energy matrix. This means that a route (path) was chosen, with performance of institutions (mills and distilleries, sector of machinery and equipment for construction mills and distilleries, automotive industry, State, corporatist organizations, R&D) and economic agents (consumers) interested, directly or indirectly, in the maintenance of the route chosen. The “interest arrangements” supported the Brazilian ethanol as the most appropriate energy option for the replacement of gasoline/diesel.

Key words: ethanol, sugarcane, path dependence, Brazilian production.

1. Introduction

The global transportation supply chain has been largely based on the oil industry (petroleum), with gasoline and diesel consumption the predominant fuel source. According to Nigro and Szwarc (2009), petroleum products account for 97% of fuel consumption in the world. For Alveal (2003), part of the innovations of the industrial organization of the last century was coming from the oil industry.

However, the consumption of ethanol in Brazil recently exceeded 50% of gasoline fueled vehicles (exclusive of natural gas or diesel). Currently, the growth of ethanol consumption is linked with the increased availability of flex fuel vehicles (vehicles that can use a mixture of ethanol or gasoline). In 2009, 90% of all cars and light commercial vehicles sold in Brazil were equipped with flexfuel technology [Brazilian Sugarcane Industry Association – UNICA (2010a); and Bioenergy Producers Association of Paraná – ALCOPAR (2010)].

Another important aspect in this discussion is the historical legacy and economics of sugarcane production in Brazil. According to Szmrecsányi (1979), the evolution of Brazilian sugarcane is intertwined with the history of Brazil. Five centuries of tradition in sugarcane production combined with recent pioneerism in the use of ethanol as vehicle fuel underscores the economic importance of sugarcane agribusiness to the regional economies of Brazil (in terms of income generation, employment, and foreign currency exchange). Indeed, sugarcane is a highly competitive and lucrative crop within the overall agribusiness sector of Brazil (Shikida et al., 2009).

Currently, sugarcane culture occupies 7.8 million hectares, or approximately 2.2% of the total arable land in Brazil. Due to geographical and climatic conditions Brazil two harvest per year (one in the Center-South, representing 90% of the total national production and

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another in the North-Northeast which accounts for the remaining 10%). The use of sugar to produce ethanol for domestic and foreign markets occurs year-round. Moreover, the country is the world's largest producer of sugarcane, producing approximately 569 million tons of sugarcane, 31 million tons of sugar and 27.5 million m³ of ethanol in 2008/09. There are roughly 350 Brazilian sugarcane mills which directly employ approximately 1 million workers. In terms of foreign trade, the country exported approximately 20 million tons of sugar in 2008 and is the world's largest exporter (foreign revenue of roughly US$ 7.9 billion per year). In terms of ethanol production, Brazil produced roughly 5 million m³ representing about 64% and 18% of domestic supply of sugar and ethanol respectively. It is estimated that the annual gross earnings of sugar and ethanol is around US$ 20 billion (UNICA, 2010a; ALCOPAR, 2010). Sugarcane within the Brazilian energy matrix accounts for 16.4% of total energy use; ahead of hydroelectricity. Further, use of ethanol fuel contributed to a reduction of roughly 75 million tons of CO₂ emissions since 2003 (UNICA, 2010a). Neves et al. (2009) estimated that the contribution of this sector to Brazilian GNP was roughly US$ 28.15 billion; or about 2% of the total GNP.

The success of contemporary sugarcane-ethanol as a future energy option to replace gasoline/diesel relates to its benefits to greenhouse gas emissions (Shikida 1997; Paulillo et al. 2007). In this context, there was a convergence of interest arrangements on the part of (1) mills and distilleries (seeking to diversify production), (2) the State (seeking to reduce our dependence on foreign oil, improve rural economies, reduce greenhouse gas emissions, and improve national security), (3) the automotive industry, and (4) the construction, machinery, and equipment sectors (seeking to increase its sales). Although the Brazilian National Alcohol Programme (PROALCOHOL - Decree n. 76.593) has faced numerous challenges since 1975, it has significantly advanced both the technology of sugarcane-ethanol production and the production of flex-fuel vehicles (Souza and Macedo, 2009). “There were gains in plantations (agriculture part) and mills/distilleries (industrial part), decreasing the cost of a barrel of ethanol equivalent of US$ 90 in the 80’s to US$ 30 today, while the oil price increased” (Veiga Filho, 2008, p.8).

The growth of flex fuel cars and the competitiveness of ethanol with respect to oil combined with the institutional involvement of various sectors around the sugarcane economy leads an analytical perspective analogous to the path dependence approach. Path dependence represents a useful conceptual approach to describe the power and influence of the past on the present; and the present on the future. According to North (1990):

Path dependence is the dependence of economic outcomes on the path of previous outcomes, rather than simply on current conditions. In a path dependent process, “history matters” – it has an enduring influence. Choices made on the basis of transitory conditions can persist long after those conditions change. Thus, explanations of the outcomes of path-dependent processes require looking at history, rather than simply at current conditions of technology, preferences, and other factors that determine outcomes (Puffert, 2008, p.1).

Thus, this study assesses the sugarcane-ethanol phenomenon in Brazil using path dependence to sort out relevant economic and institutional systems. Our hypothesis is that “orchestration” of interest arrangements and the trajectories of newly-shaped institutional sectors after deregulation was configured by the mechanism of path dependence for sugarcane-ethanol, this important product of the sugarcane agribusiness.

This manuscript is organized into four subsequent sections. Following this introduction, I outline the method and a brief review of the path dependence approach. Next, I discuss the central elements that provide results on the path-dependence analysis. I conclude the manuscripts with a summary and a set of policy implications.
2. Method

The method used in this study is qualitative research, descriptive and based on documentary/literature. Normally the qualitative method provides insights that are difficult to produce with quantitative method. The qualitative research used (in this article) involves an understanding of economic and institutional behavior and the reasons that govern such behavior (Chizzotti, 2006). In this case, there needs to be a thorough verification of the phenomena about ethanol in Brazil, to examine the particular situation under investigation.

The type of research documentary/literature is related to the collection of information on references in the sugarcane area (Gil, 2000) - database comes from both the secondary source material (available in the published literature) and primary (laws, decrees, research report, etc.).

Last but not least, this study has descriptive connotation because it seeks to describe the characteristics of a particular fact, also advancing a prognosis for the ethanol fuel. “The research descriptive has a function to observe, record, correlate and describe facts or phenomena of a reality without manipulating them. Seeks to know and understand the various situations and relationships in the social, political, economic and other aspects that occur in society” (Valentim, 2008, p.23). In this case, the use of descriptive analysis is based on the description of elements and/or characteristics that relate to development of ethanol in Brazil and the path dependence theory.

2.1. Path dependence theoretical framework: brief notes

For North (1990), the path dependence idea means that the historical background is important, specifically, to understand the current choices one must know the incremental evolution of institutions, because this choice was influenced by the institutional matrix of the past. In fact, “path dependence is a way to narrow conceptually the choice set and link decision making through time” (North, 1990, p.98-99). Path dependence sequences occur when temporally remote events determine outcomes (David, 1985).

Thus, the decisions pave the way, with new standards interacting with the old, and present and future are connected by the action of institutions that, through the dynamic of history, network externalities, the learning process of organizations and technological capabilities (innovations) can influence the future institutional framework.

On path dependence, according to Shikida and Hillbrecht (2004, p.3), “there would be some degree of dependence on the current economic performance due to initial parameters chosen by the economic agents in the past.” Therefore, it is necessary to investigate the antecedent conditions for a broader understanding of the current situation.

A similar approach had been made by David (1985), saying it is not possible to discover the logical (or illogical) in the world today, except by understanding how the world got its shape. In this context, the history matters because the past is considered irreparable and may not be reproduced in the same initial conditions, so the past shapes the present (Moreira and Herscovici, 2006).

Many trace the popularity of path dependent theories to David’s (1985) exploration of the adoption and continued use of the QWERTY keyboard. David was puzzled as to why QWERTY keyboards have dominated when more efficient options were, and continue to be, available. The answer, he claimed, arose in tracing the interconnectedness of production and demand in the typewriter market back in the 1880s. These conditions facilitated “self-

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2 This article does not aim to make a major review of the path dependence. More considerations about this theory, see: North (1990), David (1985), Zysman (1994) and Levin et al. (2009).
reinforcing” processes operating through three mechanisms: technical interrelatedness, economies of scale, and quasi-irreversibility of investment (Levin et al., 2009, p.15).

Zysman (1994), combining the institutionalism perspective of North with the evolutionary trend, points out that the national growth trajectories are historically rooted (embeddedness). In this sense, national movements are part of a process of interaction and competition; and the organization of political systems and markets, within each economy, becomes crucial in designing institutions, which reflects in the decisions of agents and, consequently, in market operation.

In this logic of Zysman (1994), Conceição (2008) says that only creating a basis for investment in a process of growth is not enough, it is necessary to build an institutional structure capable of turning it into growth, the function of community and institutional structure being fundamental in determining patterns of the innovative process and technological capability.

Technology, like market processes, is not disembodied. It develops in communities; it has local roots. The processes of learning that drive its development are shaped by the community and institutional structure, and consequently the technological trajectories can only be defined in reference to particular societies (Zysman, 1994, p.261).

“Path dependence is relevant when particular historical factors determine the institutions, organizations, and technologies that emerge. The structures of physical, human, and social capital constrain future production and wealth is always and everywhere a residuum of past activities” (Mises, 1996, p.506).

Therefore, in the design of path dependence, both, institutions and technologies, tend to follow a path historically constructed, discussing “mainly coordination problems, be it coordination to move an industry from one technology to another or from one industry standard to another” (Levin et al., 2009, p.16).

Technological change and institutional change are the basic keys to societal and economic evolution and both exhibit the characteristics of path dependence. Can a single model account for both technological and institutional change? They do have much in common. Increasing returns is an essential ingredient to both (North, 1990, p.103).

In this dynamic, the trajectory and its implications should be emphasized because, according to Enderle and Guerrero (2008, p.4), “the trajectories of economic growth are diverse and heterogeneous, and occur within a process of constant change, without knowing if will be better, or not.” Therefore, there is a need to understand the process of institutional change, using the concepts of embeddedness and path dependence.

However, we must say that the innovation process is related to the choice of a particular technology standard that develops creating a situation of lock-in (structural rigidity), in which the change becomes very difficult.

Lock-in exists where the balance of past decisions makes one particular option globally preferred. That is, it describes the outcome of path dependence. For instance, a typist that enters the market after the initial period of competition will only have one option: learn to type on a QWERTY typewriter (Levin et al., 2009, p.18).

For Arthur (1989), in the case of lock-in, the degree of difficulty in modifying the characteristics that determine the institutional and technological standards will determine its trajectory (including since the technical design until financial aspects). Because this fact, often, the institutions, according to goals, influence the use of certain technologies, creating a mechanism of path dependence with lock-in. In this sense, North (1990) considers the causes of path dependence on technology, creating situations of lock-in: the fixed costs perspective
(in this case: leading to a reduction in costs when the production increases); the effects of learning; the coordination purposes, derived from the cooperation between agents that have the same type of situation; and the adaptive expectations.

3. The economics of ethanol production in Brazil: a path dependence?

Belik (1992), Shikida (1997) and Paulillo et al. (2007) emphasized the “orchestration” of interest arrangements as a primary factor for the entry of ethanol in the Brazilian energy matrix. For Shikida (1997, p.158-159),

A bottle neck in the productive process originated by the oil crisis gave rise to an environment favoring energy alternatives. The sugarcane agroindustry crisis generated an “interest arrangements” that led the country to opt for PROALCOHOL Programme. [...] The “interest arrangement” around the PROALCOOL included: the managers of sugarcane mills and autonomous distilleries; the State; the section of machines and equipment; and the automobile industry. For the managers it was necessary to diversify the production. The interests of the State consisted of the following objectives: economy of exchange value; decrease of regional income inequalities; growth of income and job interns; and expansion of capital goods. For the section of machines and equipment, this programme was important for sale of products to the sugarcane industry. Specifically for the automobile industry, the petroleum crisis was an obstacle to the Brazilian motorway political, and the car - moved by alcohol - showed as an alternative of continuity to this model.

On the relation State-sugarcane agribusiness, Belik (1992) and Ramos (1999) call attention to the fact that this sector has a historic joint capacity, acting in accordance with the interests of the State and other private institutions to promote public policies that converge to leverage its main products (sugar and ethanol) in the national and international.

The ethanol, in the perspective of PROALCOHOL’s evolution (Shikida, 1997), after going through a period of “moderate expansion” (1975-1979, a phase dominated by the production of ethanol as an additive to gasoline, which was sponsored by incentives and subsidies) and the phase of “accelerated expansion” (1980-1985, which strengthened the incentives of the State to produce ethanol, with emphasis on the hydrated type and with a strong stimulus for the sale of vehicles that run exclusively on ethanol) showed the first phase of deceleration and crisis during the period 1986/1995. During this crisis, there was a substantial reduction of public investment in PROALCOHOL Programme and the imbalance between supply and demand for ethanol fuel, and this fact contributed to declining interest in producing vehicles run on ethanol (in the view of the auto industry) and buying vehicles run on ethanol (in the view of the consumer). It must be said that the end of 80’s and early 90's, the oil prices had fallen (favoring the consumption of gasoline), while the sugar prices were at high levels (directing sugarcane production for this commodity), important factors in explaining this critical phase of PROALCOHOL.

However, the Brazilian economy had an alteration of the State’s political profile, not only concerning the sugarcane industry but the entire economy. Starting from 90’s, Brazil developed a State with a “neoliberal” profile, also affected by a serious fiscal crisis that, according to Belik (1992), forced the contention of PROALCOHOL in terms of a reduction of incentives, subsidies, etc. Another point is related to the extinction of a public organization, IAA (Sugar and Alcohol Institute), occurred in 1990, thus finished the intervention mechanisms in productive activity, e.g., the establishment of production quotas, fixed prices for sugarcane, sugar and ethanol, subsidies to sugarcane mills, etc.

The policy of State intervention in national sugarcane complex was responsible for a delayed structure and low competitiveness that occurred during the last fifty years. The change of
policy and institutional environment, in turn, has forced companies to adopt different strategies, seeking national and international competitiveness (Belik et al., 1998, p.8).

So this crisis has given rise an another paradigm - the technological paradigm - that the sugarcane mills and distilleries are obliged to take to stay on the market, making it crucial to minimizing the costs of production, the development of new technologies and intensive utilization of the by-products to a more competitive situation (Shikida, 1997). For Fernandes and Coelho (1996, p.154), “a system of greater freedom of action will increase the market share of firms to make them more efficient than the average and thus make the industry more profitable.” In this context the process continued where the less technologically prepared firms went out of business or were incorporated by the most dynamic ones. Thus, during the 3 phases of PROALCOHOL, the costs of producing ethanol fell by 66%, with potential for a further reduction.

Changes occur in the market of this sugarcane agribusiness. According to Fortes (2009, p.1), “from 2000 to September this year, the sugar and ethanol had 99 mergers and acquisitions involving Brazilian companies”. Moreover, the foreign firm, which is about 20% today (in Brazilian sugarcane agribusiness), has begun to show that it will expand the market share, depending on the opportunities created by sector deregulation (began in 1990) and favorable expectations for growth of sugarcane plantation and production of ethanol (with high demand for ethanol because of the introduction of flex fuel car in the market). Foreign direct investment in sugarcane agribusiness, concentrated initially in the categories of “refining, sugar milling and sugar mills”, in 2002 also began to invest in the “ethanol production” category, which increased from US$ 4 million in 2002 to over US$ 1 billion in 2007 (BACEN, 2008).

From 1996 to early 2000 there was a brief recovery in the growth of ethanol production, but it was soon followed by another decline, due, in part, to the economic incentives for the use of Natural-Gas Vehicle (NGV), abundant and with low prices, which contributed to increase of the national fleet of cars run to NGV. Moreover, it is clear the new stage of rearrangement of the sugarcane agroindustry has come under the “guidance” of deregulation, in which “the state’s role has changed, he is now coordinator, not more interventionist” (Vian, 2003, p.11). Indeed, in early 1990 the price of domestic sugar was liberated; and in 1994 the quota of sugar exports was liberated; in 1997 the price of anhydrous ethanol was also liberated; the prices of sugarcane and hydrous ethanol were liberated, respectively, in 1998 and 1999 (ALVES, 2002).

From the 2000/2001, ethanol presented a good perspective of high growth, due to the need to reduce emissions of greenhouse gases (production of ethanol from sugarcane and the consumption of this product offers advantages in this respect), and an innovation that significantly changed the dynamics of the sector, the introduction of flex fuel car - which allows the use of both gasoline and ethanol, or a mix of both fuels. In 2008, 90% of all cars and light commercial vehicles sold in Brazil were equipped with flex fuel technology; that compared with 3.7% in 2003, the year in which flex fuel vehicles first went on sale in Brazil.

The figure 1 shows the evolution of total ethanol production in Brazil. From 1975/1976 to 1985/1986 there was a growth of ethanol production (average growth rate of 34.7% per year), confirming the moderate and accelerated stages of PROALCOHOL Programme. From 1986/1987 to 2000/2001 there was a deceleration, crisis and instability in the ethanol production (average growth of 1.25%), from this period on, there was an expansive second cycle for ethanol (2001/2002-2008/2009, average growth of 12% per year). For the whole period considered (1975/1976-2008/2009), the growth rate of average annual production of ethanol in Brazil was 7.7%.
Just as the “orchestration” of interest arrangements was a primary factor for the entry of ethanol fuel in the energy matrix, its technological and institutional rearrangements have conditioned certain routes, causing a mechanism of path dependence for ethanol. In this respect this paper focuses on: the analysis of environment of “orchestration” of interests; the analysis of the environment of institutional rupture that led the State to deregulate the sector, forcing the emergence of the technological paradigm as a way relevant to a more competitive situation, discussing under the path dependence theory.

Entrepreneurs of the mills and distilleries, since the beginning of implementation of the PROALCOHOL in 1975, and even during the deceleration, crisis and instability in the ethanol production (1986/1987-2000/2001), maintained its production structures directed to the sugar and/or ethanol, directing its production according to the fluctuations of commodity prices in domestic and foreign markets. In this context, it is important to point out that, even with the change of State action, the entrepreneurs of the mills and distilleries in synergy with the entrepreneurs of machines and equipment, research centers (Research and Development, R&D), organizations corporatist and also the State (even in a deregulation scenery, the State remained concerned with the issue of national energy security) continuously improved the sustainability of the production technology of industrial sugarcane in order to promote the development of agricultural and industrial productivity of sugarcane, sugar and ethanol. Thus, a great part of technological advance was due to the actions of the Center of Sugarcane Technology (CTC), and extinct National Programme for Improvement of Sugarcane (PLANALSUCAR), incorporated by University Network for Development for the Sugarcane Production (RIDESA), composed of seven federal universities (UFPR, UFSCar, UFV, UFRRJ, UFG, UFAL and UFRPE). According to Cezar (2008, p.40), “these two centers allowed that the Brazil has come out of little more than 3 thousand liters of ethanol per hectare in the late 70's, to over 7 thousand liters of ethanol per hectare currently” (today the productivity of ethanol, from beetroot, is 5.5 thousand liters/ha, while the productivity of ethanol, from corn, is 3.1 thousand liters/ha).

The production of sugarcane per hectare has jumped from 50 tons per hectare (on average) in the 70s to around 80 tons per hectare today (on average). And there is perspective for further growth in productivity of ethanol from cellulosic waste (tailings bagasse and straw cane). This, coupled with the fact the country has crops of sugar and ethanol to the market during all year, contributes to the supply of ethanol become more elastic.

Besides stimulus to technological environment of ethanol given by two research centers mentioned above, the Brazilian Development Bank (BNDES) and Center for Strategic

Figure 1. Evolution of total ethanol production in Brazil and the key aspects - 1975/1976-2008/2009 (source: ALCOPAR (2010) and research data).
Studies and Management in Science, Technology and Innovation (CGEE) (2008) point out that advances in productivity of industrial sugarcane in general, and particularly for ethanol, derived mainly from innovations from biological, physical, chemical, mechanical, and more intensive reuse of the bagasse for co-generation power, and innovations associated with new forms of work organization, production methods and management of global agricultural and industrial production. In this context, it is important to remember that these advances were also achieved by the synergy with other institutions that produce technology and research centers such as: the Campinas Agronomy Institute (IAC); Institute for Technological Research (IPT); Institute of Food Technology (ITAL); Biological Institute; and three state universities [University of São Paulo (USP), State University of Campinas (UNICAMP), São Paulo State University “Julio de Mesquita Filho” (UNESP)], which contains several courses and research groups focused on scientific and technological development of industrial sugarcane, essential to the process of expansion with increased productivity observed in this sector.

Macedo (2007), see table 1, summarizes some items that were important for the technological modernization of the production process of sugarcane and ethanol, as new and productive varieties of sugarcane, the advances in production of fertigation, mechanized of harvest, improved of fermentation and the development of flex fuel engines.

Table 1 - Some of the major technological advances of the production process of sugarcane and ethanol (1980-1990 and 1990-2000).

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<tr>
<td>The introduction in large scale of sugarcane varieties developed in Brazil (mainly CTC-COPERSUCAR and PLANALSUCAR).</td>
<td>Optimization of cutting, loading and transportation of cane.</td>
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<td>The development of the use of vinasse in fertigation.</td>
<td>Mapping of the sugarcane genome, genetic transformations.</td>
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<td>Biological controls in the production of sugarcane.</td>
<td>Mechanization of harvest.</td>
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<td>Development of a milling system with 4 rolls.</td>
<td>Surplus of electricity (that can be sold).</td>
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<td>Technology for the operation of “open” fermentation large.</td>
<td>Advances in industrial automation.</td>
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<td>Co-generation, increased production of electric power industry (self-sufficiency).</td>
<td>Advances in technical management (agricultural and industrial).</td>
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<tr>
<td>End use: ethanol specifications, E-100, transportation, blending and storage of ethanol.</td>
<td>The introduction of flex fuel engines.</td>
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With these technological advances in the production process of sugarcane and ethanol, Macedo (2007) emphasizes gains of 8% on the quality of raw material, gains of 130% in the productivity of fermentation and gains of 14% in the conversion of sugars from sugar cane to ethanol. Veiga Filho (2008) has an indicator of cost that shows the competitive gains that the learning curve of the ethanol provides in Brazil, i.e., the ethanol from Brazilian sugarcane costs US$ 0.20, the ethanol from American corn is about US$ 0.40.

Furthermore, the ethanol can be extracted from the hydrolysis and fermentation of lignocellulosates materials, called second generation ethanol, derived from the processing of lignocellulosates, in this case, can be extracted from sugarcane residues (bagasse waste and straw) as well as of forest biomass. The main programs of R&D, experimental scales of production (waste wood and organic waste in particular) are being conducted in the United States and Europe, but several studies have been started in Brazil on the use of waste from the sugarcane. According to Goldberg (2008), with the second generation of ethanol being produced in Brazil, the sugarcane agroindustry may increase the ethanol production (from 7 thousand liters per hectare currently to around 13 thousand liters of ethanol per hectare, i.e., without the need to expand the cultivated area, mainly taking advantage of the expertise and
structure in the sugarcane agribusiness). For Castro (2009), the spending on research with this second generation has been scarce in Brazil, however, billions of dollars are irrigating scientific research in the United States, Canada, Europe and Japan in search of second generation ethanol.

The US Department of Energy (DOE), for instance, is investing USD 1 billion in the construction of experimental refineries designed to transform vegetable matter into alcohol. In Brazil, only now is something similar happening with the announcement of the Bioethanol Science and Technology Center, which is to receive BRL 50 million in the next five years […]. The Brazilian investment in cellulosic ethanol, so far, is meager, which entails the risk that the country might very quickly lose the technological edge it holds today in the ethanol area (Abramovay, 2008, p.45).

In this context of search for greater productivity, the transformation of one form of energy into another form of energy, known as co-generation, is an important issue for the sugarcane sector. The bagasse (and straw too) from sugarcane can be used for bioelectricity generation, an excellent source of energy for industrial processing itself, sugarcane and consequent production of sugar and/or ethanol, eliminating the need to buy power from the distributor. This phenomenon occurs because after the extraction of sugarcane juice, it is possible to burn the bagasse in appropriate boilers, producing thermal energy that is transferred to movement of machinery and turbines, becoming a prominent item in the composition of the production costs of ethanol and sugar derived from sugarcane (Souza, 2002). “Sugar mills and distilleries have for a long time used some of the bagasse to generate bioelectricity. Burning this residue in boilers has made sugar mills and ethanol plants self-sufficient in electricity”, with the possibility of commercializing the surplus energy produced with the local distributors of electricity (UNICA, 2008, p.9). The importance of the sugarcane bioenergy chain in Brazil (composed of ethanol - 13% - and energy from the burning of sugarcane bagasse - 3%) was around, in 2007/2008, 16% of the national energy matrix (BNDES and CGEE, 2008; UNICA, 2010b). Furthermore,

With Brazilian sugarcane production reaching approximately 487 million tons in the 2007/08 harvest year, the potential for bioelectricity generation using existing technology is around 1,800 MW. […] Looking ahead, Brazil’s 2020-21 sugarcane harvest is estimated at one billion tons. This represents the potential to generate 7,600 MW using just the bagasse, or 14,000 MW if the straw is used as well. Other countries face different situations. India, for example, produces a volume of sugarcane that is comparable with Brazil, but it is used in many small-scale, low-productivity situations with nothing like the degree of industrialization that Brazil has achieved. In countries with levels of industrialization similar to Brazil, for example South Africa, Australia and Thailand, the problem is low volumes of sugarcane production. Other countries in Central and South America are relatively small producers (UNICA, 2010b, p.1).

The search of development of new competences to increase the technical efficiency of ethanol was also applied to other sectors. There was concern about the modernization of the organizational and institutional firms, looking for other forms of corporatist coordination with the public and private sectors, for example in the development of UNICA, São Paulo (UNICA members answer for more than 50% of all ethanol produced in Brazil and 60% of overall sugar production) or other representations in other states of sugarcane agribusiness [ALCOPAR, Paraná, Alcohol Manufacturing Industry’s Union of Minas Gerais (SIAMIG)/ Sugar Industry’s Union of Minas Gerais (SINDACÚCAR-MG), etc.]. The Sectional Council of Productive Chain of Sugar and Alcohol, created by the Ministry of Agriculture, Livestock and Food Supply (MAPA), in May 2003, consisting of employers' representatives, government officials and representatives of the working class, is another institutional arrangement that aims to discuss the issues chain collectively and find solutions to their problems.
The main actions of the Council is study occurred in the sense of requesting alterations in the technologic, institutional and organizational environment aiming a fall of dealing costs, mainly in relation to the informational level of the members. [...] it is noticed that most of the meetings of the Council deals with the requests in relation to the alterations in the institutional environment, mainly to what relates to the taxes aspects (Gonçalves Jr. et al., 2009, p.184).

The CONSECANA (Sugarcane, Sugar and Alcohol Producers' Council), existing in São Paulo, Bahia, Alagoas, Pernambuco, etc., is a nonprofit civil association, with statute and its regulations, whose main purpose is to divulge monthly reference values of the price per ton of sugarcane - based on the prices of final products (sugar and ethanol) obtained by this raw material. For Zylbersztajn (2009, p.13), the “CONSECANA is responsible for negotiating contract terms between farmers and processing industry, and once approved are generally adopted. The model is showing successful results and is being adopted by other agro-industrial chains”.

In the reference of path dependence there is evidently an evolution in terms of technological and institutional trajectories privileging the search of complementary competence (North, 1990). This is the case of the search for greater ethanol productivity, with technical improvements, and also in creating new institutional arrangements (Sugarcane, Sugar and Alcohol Producers' Council, UNICA, CONSECANA, etc.), aiming not only organize the sector, such as defending the interests of sugarcane, sugar, ethanol and bioelectricity. Indeed, these new forms to reconcile the needs and interests of those belonging to the sugarcane agribusiness show the institutional innovations that the industry has done to adapt to the real world. For Enderle and Guerrero (2008, p.4), “institutions are usually a routinized process of human behavior prevalent in the social, cultural, political and economic life, which evolves through a process of selection and adaptive.”

Besides the technological gains in mills/distilleries, the sector of machinery, tractors, harvesters and trucks, also articulated institutionally with the sugarcane agroindustry, (because it is the equipment supplier), has been perfecting the technology of transportation, planting, harvesting and processing industry in the various departments of sugarcane agribusiness. As an example, the industrial units have been making improvements to the replacement of high-pressure boilers (favoring the co-generation of energy), and modernizing the application of automation in machinery and electronic equipment (Bouças, 2008).

This behavior of the industry of machinery, tractors, harvesters and trucks, related to the sugarcane agribusiness, shows a commitment to the pursuit of competitive results also found in the upstream sector. As the new technical choices are a function of history, which derives from the institutional environment and its dynamic, in this case, the sugarcane agribusiness also occurred positive externalities from the upstream sector. In this type of dynamic interaction, the whole economy wins, because there is a policy that favors innovation in one segment that also favors another segment, thus the advances in the upstream sector reflect positively in the sugarcane agribusiness, and also improve its technological capabilities.

Another major player in the institutional environment that contributes to the ethanol generates a mechanism of path dependence is the automobile industry, especially after the introduction of the flex fuel car. With the frequent instability of oil prices in the world, and the need to reduce the emission of pollutants, research began in the late 80’s in the United States, Europe and Japan to develop flex fuel technology (Siqueira and Siqueira, 2004).

The flex fuel vehicles were launched in Brazil in 2003. They have engine management systems that precisely identify the presence of gasoline and ethanol, in any proportion, and automatically adjust the operation of the engine to accept the fuel mixture it is receiving at any given moment. There are various types of flex fuel technology. In the United States, for
example, flex fuel vehicles more commonly have an ethanol sensor in the fuel tank itself or in the fuel line leading to the engine, while the Brazilian system uses a sensor that measures the degree of oxygen present in the exhaust. [...] The flex fuel concept makes it possible to use ethanol in countries where the distribution infrastructure is less widespread, for example the United States, and it also gives the consumer the freedom to choose his fuel in countries like Brazil where ethanol is more widely available. Ethanol pumps were installed at all filling stations throughout Brazil starting 1976, at the beginning of the PROALCOHOL programme. Today, all of the country’s roughly 33,000 filling stations have at least one pump offering pure hydrated ethanol (E100). At the start of 2008, the Brazilian car buyer could choose between 63 flex fuel models produced locally by 10 of the world’s leading vehicle builders. Flex fuel motors are also being adopted in hybrid vehicles that operate with twin propulsion systems that have internal combustion and electric motors. In this case the flex fuel system offers the potential to further reduce emissions of CO₂ and other pollutants, in particular those that cause global warming (UNICA, 2010c, p.1).

This is a situation where a technological standard (in this case the flex fuel technology) is generalized and improves day by day, making it extremely difficult to change to another technology, leading, consequently, the phenomenon of path dependence, i.e., the fact that the choice in present is conditioned by past choices, in which the good results of ethanol technology were decisive.

The behavior of ethanol shaped by institutions and economic agents in Brazil cannot do without an analysis of state action. The State, whose primary interests in PROALCOHOL, is summarized in: the quest for energy security; foreign currency savings; reduction of regional income disparities; domestic income growth; job creation; and expansion of production of machines and equipment industries, now acts more as a regulator of ethanol economy, which means that the production and marketing of sugarcane, sugar and ethanol are not under control of the State.

The development of this notable distribution infrastructure resulted from efforts initiated in the early days of the Proalcohol programme and was consolidated over time. It is important to emphasize that the Brazilian experience with bioethanol would not have been successful without the political will to create such infrastructure and without the support of fuel distribution companies and Petrobras (Brazilian State Oil Company), which for many years was responsible for the purchase, blending and distribution of pure bioethanol mixed with gasoline (BNDES and CGEE, 2008, p.64).

In terms of public policy, a mechanism to support the ethanol sector is performed through the Financing Programme for Storage of Ethanol and through policy incentives for flex fuel cars, in order “to internalize the market price of the environmental benefits provided by the vehicle that uses or can use only ethanol” (UNICA, 2007, p.29). Also according to UNICA, the ethanol fuel taxation focuses on producer and distributor of fuels, and the case of ethanol exportation, hydrated or anhydrous, there is no taxation on account of constitutional tax immunity. The Contributions for Intervention in the Economic Domain (CIDE), “with procedures of tax exemptions and regulations, has contributed to ensuring the competitiveness of ethanol with gasoline” (PAULILLO et al., 2007, p.542), especially in the obligatory mix of ethanol in gasoline, showing that the relationship between the state and sugarcane agroindustry still maintains certain corporatist mechanisms to promote greater energy security.

In this context, the Decree 3.546 (2000) created the Inter-Ministerial Sugar and Alcohol Council (CIMA), integrated by the Ministry of Agriculture (which heads it), as well as the Ministries of Finance, Development, Industry, Foreign Trade, and Mines and Energy, whose scope is to make policies to suit the participation of sugarcane products in the Brazilian energy matrix, seek economic mechanisms necessary for self-sustaining industry and promote scientific and technological sector. “One of CIMA’s more important responsibilities is to
specify and periodically revise the bioethanol content of gasoline, within the 20% to 25% range” (BNDES and CGEE, 2008, p.152).

In order to expand the participation in the ethanol market share, Petrobras (Brazilian State Oil Company) will invest US$ 1.5 billion into biofuels, between 2008 and 2012, and 46% in pipelines (ethanolduct). One of the ethanolduct will link producing areas of Goiás, Minas Gerais and São Paulo to the ports of Rio de Janeiro and São Paulo, the other ethanolduct will link producing areas of Mato Grosso do Sul and Paraná to the port of Paranaguá (PR). Both investments provide for public-private partnerships (Goldberg, 2008). Völz et al. (2009) point out that the transport of ethanol for export is carried out through trains and/or trucks, and this type of transport is expensive for the logistics process. With the implementation of the ethanolduct, transport costs tend to reduce 70%, further increasing the competitiveness of the sector in Brazil.

Trying to solve logistical problems, Petrobras and other companies encourage energy policy tied to ethanol, and search for new technological capabilities conditioned by historical trajectory (in this case, the need for more competitive dynamics for ethanol). This is linked to the theoretical framework of path dependence in that it allows lower transport costs from the choice of a particular technological standard such as the ethanolduct. Another interesting aspect is that the core business of Petrobras is also progressing on ethanol, showing the expression that this fuel is having on the national energy matrix.

To promote the goals of the Programme, the Brazilian government has employed various policies through the years. These include requiring Petrobras, the state owned oil company, to purchase a set amount of ethanol; tying the pump price of a liter of ethanol to a percentage of the price of gasoline (originally 59%, later increased to 80%); and requiring Brazilian automakers to produce dedicated ethanol vehicles that could run only on 100% ethanol (Seelke and Yacobucci, 2007, p.11).

Environmental issues are also linked to the state interest arrangement, because Brazil is a signatory of the Kyoto Protocol\(^3\), which sees the use of ethanol as a possibility of reducing emissions of GHG. Therefore, “in 2007, ethanol production and use in Brazil reduced emissions of GHG by about 25.8 million tons of CO\(_2\) equivalent. Ironically, under the Kyoto Protocol, the use of sugarcane ethanol is not generating emission abatement credits” (UNICA, 2008, p.12). For Saldiva et al. (2009, p.26), “damage from gasoline to public health is enormous: if all cars in São Paulo city only ran on this fuel, without ethanol, there would be more than 400 deaths per year due to higher pollution”. Another benefit of ethanol is the comparative relationship between the renewable energy produced and the fossil energy used, which is 8.9 for sugarcane ethanol in Brazil, when considering the ethanol (USA) from corn, this ratio is between 1.3-1.8; for ethanol from beet (such as produced in Germany) this ratio is 2.0; the production of gasoline and diesel results in negative efficiency (UNICA, 2010a).

Prospects which threaten the path dependence of ethanol have been major challenges associated with establishing an international market for this commodity. While the technological path dependence is an opportunity to consolidate the international market for ethanol, given the improvement of the learning curve observed in the production and use of alternative fuel, there are restrictions on trade in the product.

\(\ldots\) there are many challenges associated with the creation of an international bioethanol market. For example, Legal Tariff settings and production quality standards can affect the opportunities of developing countries in the international bioethanol market. Potential trade opportunities are reduced by measures that focus exclusively on enhancing production in

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\(^3\) Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005; it is an international treaty, linked to the United Nations Framework Convention on Climate Change, for reducing greenhouse gas (GHG) emissions by 5.2% against 1990 levels over the five-year period 2008-2012.
industrialized countries, or by protectionist measures designed to limit market access. There are concerns that tariff escalation on biofuels in industrialized country markets force developing countries to export energy raw materials, such as unprocessed molasses and crude vegetable oils, leaving the more profitable value-added industrial phase of biofuel production to the importer countries (BNDES and CGEE, 2008, p.252).

Indeed, there is no prospect of international regulation for the establishment of general patterns of alcohol-and-gasoline mixture, and even with technological advances across a growing learning-by-doing, in many countries biofuels still have a higher cost than those derived from oil (UNICA, 2007; Pires and Schechtmann, 2009). These specific questions make the formation of a world market for alcohol with several players difficult. “You cannot disregard the prospects of the pre-salt in Brazil (it is estimated that the pre-salt contains the equivalent of about 1.6 trillion cubic meters of gas and oil. This number is more than five times the current reserves of the country), which in some years will require major investments in extraction and refining of oil that will substantially increase production” (Jank, 2009, p.7). Although ethanol has many institutions that offer political orientations (resulting from the ministries of Agriculture, Finance, Development, Industry and Foreign Trade and Mines and Energy), this becomes problematic when there is lack of harmony (or asymmetric information) between ministries. Moreover, the technology development of electric cars has emerged as an alternative technical and environmentally correct to enter the automotive market, point out some predictions. “A report by IDTechEx, a research consultancy based in Cambridge, England, reckons a third of the cars made in 2025 will be electrically powered in one way or another. If that trend continues, liquid fuels might become as obsolete as photographic film” (The Economist, 2009, p.1). There is also the option of hybrid car that can run either by combustion or on electric power, because there is an electric motor coupled to a propulsion fuel (gasoline, alcohol, etc.). Because the electric motor recharges automatically, the results in terms of fuel economy is clear (Averbukh, 2007).

Disadvantages, such as reduced autonomy of electric cars and lack of an extensive network of energy supply for this type of vehicle are being worked on by companies in this activity, it is necessary “to keep the car all-battery, to introduce a network of battery-exchange stations similar to the existing network of petrol stations” (The Economist, 2009, p.1).

The figure 2 summarizes the main aspects of the behavior of ethanol shaped by institutions and economic agents in Brazil (path dependence). With the implementation of the National Alcohol Programme (PROALCOHOL), and after stages of growth and challenges, ethanol has become part of the Brazilian energy matrix. This means that a route (path) was chosen, with performance of institutions [mills and distilleries (1), sector of machinery and equipment for construction mills and distilleries (2), automotive industry (3), State (4), corporatist organizations (5), R&D (6)] and economic agents [consumers (7), seek to save money and save non-renewable resources] being interested, directly or indirectly, in the maintenance of the route chosen. This convergence of interests has given support to the Brazilian ethanol (figure 2 shows a complex network of interests between institutions and economic agents, whose the development of ethanol production has positive effects for all). Furthermore, the institutional matrix of ethanol is, at the moment, locked in (which makes the technical and economic development of other similar sources/alternatives difficult), reinforcing the character of path dependence - however there are still perspectives that threaten the ethanol (portrayed in the figure). The past history of those institutions listed above, because they are linked to stocks of knowledge and technological capabilities they have acquired throughout their trajectories, are in a process of interaction with the ethanol economy, and are defining the institutional matrix that supports the current ethanol, while at the same time shaping the future institutional matrix.
Entrepreneurs of mills and distilleries
(1)
They maintain its productive structures focused on the sugar and/or ethanol, and seek to improve agricultural-industrial productivity in cooperation with research centers (public and private) and upstream sector.

Entrepreneurs of machines and equipment
(2)
Articulated institutionally with the sugarcane agroindustry, have been improving the technologies of transport, planting, harvesting and processing industry, bringing gains for the sector.

Automotive industry
(3)
After decades of experience improving engines designed for ethanol, it is incorporating intensive use of electronics in advanced systems; responsible for the development of “flex-fuel” engines.

State
(4)
It seek adequate participation of sugarcane products in the Brazilian energy matrix, developing regulatory mechanisms for self-sustaining agroindustry and promoting scientific and technological sector.

Corporatist organizations
(5)
Mills and distilleries in collective organizational forms, aiming not only to organize the sector, such as defending of products (sugarcane, sugar, ethanol and bioelectricity). E.g., UNICA, ALCOPAR, SIAMIG, Sectional Council of Productive Chain of Sugar and Alcohol, etc.

R&D
(6)
R&D is the main institution responsible for technological capabilities obtained by sector. It serves, through an active base of scientific and technological development, the demands of units, upstream sector, automotive industry and State. Composed of public and private institutions.

Consumer
(7)
Consumers are encouraged to consume ethanol by fuel prices that internalize the environmental benefits of this product (lower taxes). With flex fuel, the driver chooses the proportion of ethanol-gasoline.

Threats to ethanol
- Despite growing interest in renewable fuels, international trade in ethanol remains small (around 5 billion liters).
- Pre-salt (it is estimated that the pre-salt contains the equivalent of about 1.6 trillion cubic meters of gas and oil. This number is more than five times the current reserves of the country).
- Many institutions are ministering policy guidelines in the energy matrix.
- The development of electric car.

Figure 2. Key aspects of path dependence on ethanol fuel in Brazil (source: research data).
4. Conclusions

This study aimed to analyze the relationship of path dependence in economic and institutional system of ethanol in Brazil. The hypothesis was that “orchestration” of interest arrangements, the trajectories and the institutional sector’s new shape after deregulation was configured by the mechanism of path dependence for this important product of the sugarcane agribusiness.

First of all, this hypothesis was confirmed. The interaction dynamics shown in figure 1, behavior of ethanol shaped by institutions and economic agents in Brazil, represents the “orchestration” of interest arrangements observed in the sugarcane agroindustry. The history, or the path dependence, showed that the interest arrangements supported the ethanol as the most adequate energy option for the substitution of petroleum oil derivatives. The ethanol and sugarcane bagasse represent 16% of the Brazilian energy matrix. The ethanol use in Brazil has grown, despite the phase of deceleration, crisis and instability in the ethanol production (1986/1987 to 2000/2001), especially since the introduction of Flex-Fuel Vehicles in 2003.

Now, for the ethanol in Brazil, it is important to grant attention to costs, to the development of new technology and to take advantage of the by-products (mainly bagasse), because the economy is dynamic. Even with this history of the sugarcane, economy has begun with the colonization of Brazil, but threats to ethanol hegemony exist (e.g., with the development of the electric car).

In terms of public policies become necessary more actions for promoting R & D, dissemination of technologies, stimulate the improvement of infrastructure, logistics and managerial skills required in well developed ethanol production systems. Therefore, it is worth noting that Brazilian expertise can pave the way for international market of ethanol.

Finally, the Brazilian experience in the ethanol production was accumulated over many decades. Then, the most important recommendation at this article is suggest more research, especially about the international market, because the ethanol could play an important role in the energy matrix of many countries.

References


