CUIBE
JGBC JOURNAL FOR GLOBAL BUSINESS AND COMMUNITY
ISSN: 1934-4244

Co-evolution of Institutional Frameworks and Technological Capability Building across Different Industrial Regimes

The Ethanol Industry in Brazil

Carlos Alexandre Matias
Gabriel Sena de Souza
Paulo N. Figueiredo

gabriel.barreto@fgvmail.br

Fundação Getúlio Vargas

Escola Brasileira de Administração Pública e de Empresas (EBAPE)

Introduction

This paper examines the role played by macro and meso institutions, research institutes and universities in the process of accumulation of technological capabilities, along distinct regimes experienced by Brazilian industrial economy: the regime of industrialization by import substitution and the open economy regime both differed by the role of government in economy. The study observes Brazilian ethanol industry from sugarcane during the period 1970 to 2009 and its events caused by political-economic changes from 1990s.

Although debate stays alive, influences and impacts of formal and informal institutions on process of accumulation of technological capabilities and innovation in industries of developing countries are disparaged by literature. It is clearly stuck in a static approach, concentrating efforts on understanding of mechanisms of intra and inter organizational learning and their different roles in the accumulation of technological capabilities within firms, often located at the frontier of international technology.

During the last four decades, it has been possible to observe the gradual formation of a solid institutional base in the Brazilian ethanol industry, besides the evolution of technological capabilities and the emergence of a new technological trajectory to the world (Dantas & Figueiredo, 2009). Regarding the creation of a sustainable energy system in Brazil, new to the world, a number of issues about the co-evolution between the path of accumulation of technological capabilities and institutional factors in the industry arise. The search for answers to these questions drives the study in order to examine the co-evolution of the main elements of institutional framework and trajectory of accumulation of technological capabilities covered by the ethanol industry in Brazil.

Consistent with Dantas and Figueiredo (2009), sections have been structured into four periods, which marked the development of institutional and technological sector. The first one, between 1975 and 1978, covers the period of establishment of the sector and the first phase of National Alcohol Program (Proálcool). The second period, from 1979 to 1985, is characterized by strong industrial growth, caused mainly by its consolidation. The third one, between 1986 and 2002, is represented by collapse of oil prices in 1986, followed later by the stagnation of Proálcool. Finally, the last period, from 2003 to 2009, is marked by resurgence of ethanol production in Brazil and the expansion of the fleet of flex fuel cars.
The present article aims to offer, as a complementary alternative, a technological and institutional explanation to the referred dynamic phenomenon, trying to fill the gap left by academy regarding the study area. It was possible to analyze the existence (or absence) of an association between the institutions and the paths of technological capability accumulation in the ethanol sector, basing on results obtained by applying the empirical model.

Conceptual Framework

Some of the main studies, which have modeled this work, are here presented. Section 2.1 reviews the knowledge basis of the institutional influence over technological capabilities accumulation. Section 2.2 reviews studies that feed the conception of technological capabilities over developing countries, used in this article.

Institutional Framework

The institutional perspective can help companies located in developing countries, to increase their competitiveness and also to gain comparative advantages (Peng, Wang & Jiang, 2008). In this direction, the evolution of technological capability accumulation is related to the conditions imposed by institutional forces in certain industries. Nevertheless, organizations also have a building role over the institutional context of their industries. So then, the innovation process is influenced by the co-evolution between institutions and the accumulation trajectory of technological capabilities. However, the variety of technological routes operated by organizations, depends on particular sector bodies within a given period.

Perhaps, due to the amorphousness of the term "institution", there is a huge scarcity of empirical studies concerned with the technological phenomenon in institutional bias (Bell & Figueiredo, 2010). Emerging countries suffer even more, for even fewer studies of this nature.

The institutional perspective (Evans 1995; Lall 1992; Murmann 2003; Nelson 2008; Nelson and Sampat 2001; North 1990; Peng et al 2008; Scott 2001), in this context, complements the purpose of analysis the institutional and technological co-evolution and performance of industries in developed and developing countries (Ariffin & Figueiredo 2004; Dantas & Figueiredo 2009; Figueiredo, 2003; 2009; 2010; Hobday, 1995; Kim 1997; Lee & Lim 2001). North (1990) defines institutions as the rules of the game, where the formal and informal rules are created and evolving over time and influencing the characterization of the game. Murmann (2003) was also taken into consideration, supplementing the term in this paper, describing it as actions, rules, social structures, practices, ideas and values, persistent over time and spread beyond the border of a single organization.

This study recognizes the importance of learning mechanisms for the process of accumulation of technological capabilities (Figueiredo, 2003; 2009; 2010; Ariffin & Figueiredo, 2004). The analysis of other factors, such as the role played by components of the institutional framework on paths of technological capabilities accumulation, complements the understanding of the technological developments in Brazilian ethanol industry.

Finally, following Bell and Figueiredo (2010), institutions are classified into macro (regimes consisting of complex public policy), meso (the political and bureaucratic structures) and knowledge-based institutions (institutes of research and universities).

Technological Capability Accumulation

Technological capability is the essential element of this work, understood here as defined by Figueiredo (2009): a resource stock, based on technological knowledge, stored in at least four components: technical and physical systems; management, as well as tissue and organizational systems; people or human capital; its products and services. Inspired by definition of Bell and Pavitt (1993), Figueiredo (2009) distinguishes the activities of operation of existing technologies (production capacity) and activities of creation or modification of new technologies (innovation capabilities), defining the technological capacity as the ability to create, adapt, manage and generate the four components above and their interaction.

Bell and Pavitt (1993), cited above, becomes important when differs the nature of technological learning by firms of developed and developing countries. They claim that firms of industrializing countries have to pursuit technological accumulation, through acquirement of knowledge, abilities and experience both essential for creation of incremental and radical innovations. Still, the authors define technological accumulation as the ability held by countries to generate and manage the process of changing the technological capabilities.

We must remember that a process of accumulation is not necessarily accompanied by linearity, perhaps by a single trajectory. Companies typically acquire technological capabilities to operate and use existing technologies at first, while most innovative skills are acquired later. However, one can undertake movements towards the frontier (catching up) and, later, per pass (Overtaking) companies already on technological frontier, according to prospect of Figueiredo (2009). In addition, companies can also trigger a qualitative shift in technological trajectory of its industry, moving itself into new routes and discontinuous technological alternatives, if compared to precursor routes taken by others.

Operationalization of Constructs. This paper uses a model analysis based on Figueiredo (2003; 2010), Ariffin and Figueiredo (2004) and Miranda and Figueiredo (2010) to identify, qualify and classify the technological capabilities of production and innovation in the Brazilian ethanol industry. The reference model is structured over different types (production and innovation) and stages (1 – 5) of innovative technological capabilities. These stages are named as (1) production innovative; (2) basic innovative; (3) intermediate innovative; (4) advanced; and (5) world-leading. The stage-structured model aims to measure the accumulation of technological capabilities of production and innovation.

In addition to this classification, it includes three concepts drawn from OECD (1997), related to the novelty degree of innovation: new to the company, new to the market, and new to the world. As a minimum requirement for an innovation, the change must be considered new for the company itself. The concepts new to the market and new to the world are related to the fact that certain innovations could already be implemented by other companies. Moreover, a company can be considered pioneer, by implementing such novelties in its markets, industries, or in the world.

These production and innovation capabilities are allocated into two activities related to the cane cultivation and ethanol production process. The agricultural stage of the technological route is made primarily by development of seedlings, planting, harvesting and transportation of sugarcane. The industrial stage, in turn, includes grinding, fermentation and distillation process. The skill levels are defined by the degree of complexity and novelty of the activities and technological projects that one is able to undertake.

Empirical Context

As fuel, ethanol is not a novelty. Since the first moment of automotive industry, ethanol could be used. But, due to strong economic competitiveness of petroleum, it did not stand long on that market, being that gasoline is widely adopted as auto's fuel. However, the environmental preoccupation and the search for energetic security, over time, have changed the scenario, and ethanol recovered strength. Besides absorbing greenhouse gases over its productive chain, it

becomes more reliable than others since it constitutes a renewable source of energy. It has emerged, so, as a panacea *vis-à-vis* the burst of a series of shifts on society, over plenty of dimensions.

The feedstock used in biofuel production is the biomass derived from plants, animals, microorganisms and organic waste. Despite the lack of consensus on the classification of biofuels, IEA (2009) separates the different generations of biofuels, according to the level of development and the materials used in its production process. The first generation of biofuels includes mature technologies applied in the production of ethanol from seeds, grains and plants. The second generation of biofuels comprises a range of biofuels produced from lignocellulosic materials, namely fiber, straw, wood and grass. The third generation of biofuels often involves the routes for production that are still in their early stages of research and development, as derived from algae and hydrogen.

With regard to first generation of biofuels, the knowledge used to produce ethanol, reached the highest levels of technological and commercial maturity. Urging breakthroughs on its productive process, technologies from second generation have a high potential to revolutionize the international biofuels production, not reaching commercial scale yet. U.S, Brazil and Europe could be cited as the most involved in R&D efforts, in this direction.

Ethanol production is concentrated in few countries. The U.S. and Brazil stand out among the largest producers. The U.S. production, based on corn, and Brazil's production, based on sugarcane, represents over 87% of world ethanol production. Europe (France, Germany, Spain and others) stands at third place, having produced 2.7 billion liters of ethanol. In 2002, China started the local production of ethanol and achieves an output of 2.0 billion liters in 2009, occupying the fourth position. The Brazilian ethanol industry is taking a major role in biofuels context, for economic, technological and social reasons.

The superiority of Brazilian ethanol is a reflex of the huge difference between its production costs of one liter of biofuel in comparison to several producers' countries. For example, in Brazil, the production of one liter of ethanol from sugarcane costs $0.31/liter, while the U.S. ethanol from corn costs about $0.75/liter, reaching a maximum of $0.87/liter in England and Spain, whose ethanol production comes from wheat.

Methods

The necessity of the case study arose from the need to examine empirically the technological and institutional sector of Brazilian ethanol, in order to understand the complex interaction between these two factors. The strategy adopted in this article is rooted on individual explanatory case study, justified by the nature of the issue: "how." Lack of control over the events of the case and its longitudinal characteristic also were crucial in decision to use the strategy above. This research aims to study certain conditions specified by theory over time, not pursuing a full interpretation of the events triggered in this industry. Besides these, we intend to include consideration of impacts and outcomes achieved through the interaction between these two variables. The study will include a combination of quantitative and qualitative elements.

The analysis of the trajectory of technological accumulation in the Brazilian ethanol between 1970 and 2009 required the use of different data types. The case study used primary sources, as transcripts of interviews with managers of companies and research institutes, industry experts, in addition to magazines with outstanding professionals. Secondary sources were also used, through expert reports on the agribusiness sector of Brazilian ethanol, publications, websites and documents provided by companies studied, besides documents and reports from governmental agencies.

To analyze the accumulation process of technological capabilities and the main elements of the institutional framework, the evidence were initially structured by matrices, whose rows represent the activities or technological functions studied, while the columns, the period of time examined. Each of the cells identified projects and activities that represent the level of technological innovation and production functions for agricultural and industrial products for a period of time, as well as the key mechanisms used by Brazilian government.

After that, the levels previously defined were classified, into each interval of five years, in order to obtain the final result of the evolutionary accumulation of technological capabilities of production and innovation in agricultural and industrial areas. In parallel, we analyze the implications, impacts and interaction between elements of the institutional framework and the accumulation trajectories of technological capabilities, seeking for a relationship of cause and effect between these two variables examined here.

Findings

The findings expose evidences realized on Brazilian ethanol industry, during the last four decades, among two sections. Section 5.1 aims to express events which occurred over the industrial regime of import substitution, as section 5.2 relates events which stem from the liberalization of Brazilian economy.

Industrial regime of import substitution (1970-1989)

The institutional and technological co-evolution of the referred sector, between 1970 and 1989, is described here into two subsections, given the necessity to analyze each dimension of the institutional framework and to discern, the technological shifts occurred on different stages of ethanol production.

Evolution of institutions: 1970-1989. Through a macro and meso institutions perspective, the emergence and transformation of institutions and technology of this sector in Brazil have a history marked by variations in the relationship with the government sector, according to the circumstances and interests of each season. It begins to be built in 1933, when government created the Institute of Sugar and Alcohol (IAA), which defined the rules of the game by imposing restrictions and limiting the action of the business sector. The interventionist government institutionalization process followed requests from producers.

In the 30s, a decree signed by the president kicked off the major mechanism of relationship between government and the Brazilian ethanol industry. It was substantiated on Brazilian government determination to mix ethanol with gasoline, which importance used to vary over

time. The decree, as well as subsequent interventions intended to reduce the impact of dependence on petroleum-based fuels and also use the surplus production of the sugar industry (BNDES & CGEE, 2009).

In the 70s, the impacts of the first oil crisis guided changes on decision making process towards the production and marketing of alcohol in Brazil, when it used to import more than 80% of oil. The Alcohol Program was presented as an alternative to mitigate effects of the shock, in 1973, when oil prices skyrocketed. The saturation of the international sugar market also led to the fall in the prices of marketing of this product (CGEE, 2009).

The second phase of the Program was marked by the second oil crisis, when prices of this commodity were shaken due to Iranian Islamic Revolution, on 1979. In this context, the Brazilian government created a new set of tax arrangements to minimize the effects of the period and stimulate the expansion of production of anhydrous alcohol, hydrated and ethanol-fueled vehicles, affecting the entire sugarcane sector (Fonseca et al, 2007).

In turn, the third phase of the Alcohol Program, between 1986 and 1995, included a period of reduced investment in the program. The increase of foreign debt and inflation rates in the country also affected the financial capacity of the government and resulted in the fall of the government investments in the ethanol sector (Fonseca et al, 2007). At 1985, prices also initiated a downward trend, influencing the reduction on alcohol price. During this period, Fonseca et al. (2007) also highlighted the rise in sugar prices in the international scenery, encouraging many farmers to reduce production of alcohol.

At the end of this stage, however, the demand for ethanol continues its expansionist phase due to the incentives for the purchase of alcohol cars, what caused conflicts with the ethanol's production (Fonseca et al., 2007). The government had to adopt alternative measures, such as import for addition of methanol to gasoline or hydrated ethanol, to avoid a supply crisis (Bacha & Shikida, 1999). This phase of slowdown and crisis characterized the formal end of the Alcohol Program, marked by the end of subsidies to producers, the price more attractive to produce sugar for export, the stagnation of production and falling prices of alcohol, despite the demand for hydrous continue to grow (CGEE, 2009).

Public institutions, federal and state agencies, such as research institutes and universities, and besides these private companies have taken a very important role in technological development in the agribusiness sector of ethanol from sugarcane. During this period, the trajectory of technological accumulation of sugarcane was carried in large breeding programs of sugarcane, promoted mainly by Copersucar Technology Center (CTC), the National Program for Improvement of Sugarcane (Planalsucar), created by the Institute of Sugar and Alcohol (IAA), and the Campinas Agronomic Institute (IAC).

These institutions dedicated efforts particularly in the agricultural stage, involving the breeding, agricultural mechanization, management, biological pest control, recycling of effluent and agricultural conservation practices for increased performance (BNDES and CGEE, 2008).

Evolution of technological capabilities: 1970-1989. One of the first efforts towards technological capabilities accumulation, in agricultural sector, was substantiated in the creation of Planalsucar. Its main project was focused on investigation of new cane varieties, what represents innovations to market, classified at Level 4 (Advanced Innovative).

During the 1970s and 1980s, Ridesa (2010) also describes the production and testing of machinery and equipment models, which improved the conditions of cutting, loading and transportation of sugarcane in areas of slope, technological capabilities classified at Level 2 (Innovative Basic). The structure of R&D stood out by the production of certified seedlings, analysis of soils and advice to assembly plants in their own laboratories, which resulted in the accumulation of innovative capabilities qualified at Level 3 (Intermediate Innovator).

Parallel to Planalsucar, the creation of the CTC has also boosted the process of accumulation of technological capabilities to innovate more advanced, new to the market, classified as Level 4 (Advanced Innovative). CTC realized an intense R&D for the development and selection of seed sugarcane, through activities of searching, intersections, and a careful selection of seeds from Australia, Barbados and Jamaica.

During the formation of the ethanol industry, from 1975 to 1978 and later, Dantas and Figueiredo (2009) highlight the efforts to adapt existing technologies through activities of design and engineering, new innovations for the company, classified as Level 3 (innovative Intermediate). Once new technologies have been introduced, Proálcool became responsible for changes in equipment to solve problems and production bottlenecks, expanding ethanol's production, and for adding the dehydration step, responsible for production of anhydrous alcohol. These engineering efforts to adapt and improve processes and products have resulted in innovations for the company, classified at Level 3 (Intermediate Innovator).

During the second phase (1979-1985), Proálcool encouraged the expansion of production in industry machinery and equipment for the ethanol industry. The government redirected the strategy for the production of hydrated alcohol, used in cars powered only by alcohol. The main technological change continued to be executed through activities as re-design and engineering processes, resulting in the introduction of successive improvements in the processes of ethanol production. These changes are classified into innovations for the company, at Level 3 (Intermediate Innovative).

Liberal Economy Regime (1990-2009)

The institutional and technological co-evolution of the referred sector, between 1990 and 2009, is also described into two subsections, to analyze each dimension of the institutional framework and to differentiate the technological shifts occurred on different stages of ethanol production, in a general way.

Evolution of institutions: 1990-2009. The period of deregulation of the ethanol industry is analyzed by Dantas and Figueiredo (2009) from a time perspective, segregated into two phases: from 1986 to 2002 ("slowing down") and 2003 to 2009 ("phase of revival"). During the first phase of sector deceleration, institutional changes (such as the emergence of the Federal Constitution of 1988, inspired by the 10 guidelines of the Washington Consensus) significantly

affected the rules of the game. It resulted in considerable reduction of the government role on economy, in openness to imports of goods and services and in the entry of venture capital in the country, impacting the entire productive chain of ethanol.

Changes, however, did not develop smoothly and regularly, triggering a series of conflicts of interest and opinions among several industry groups. In this turbulent context, a series of institutions were created to unite producers and to help them to face the difficulties arising from deregulation, strengthening its representation, as UNICA and CEPAAL. The creation of other institutions, and as a consequence, the spreading of power through new players, reflected the government posture.

The year 2003, in turn, marks the revival of the Brazilian ethanol industry. This year, the automotive industry introduced vehicles with flex-fuel engines (Fonseca et al., 2007). The owners of these vehicles, according to their will, had the option of filling their cars with gasoline, mixed with anhydrous ethanol, or only with hydrated ethanol. The expansion of participation in flex-fuel vehicles in the Brazilian fleet boosted the momentum of investment in the productive sector of ethanol from sugarcane. For that, BNDES disbursed significant funding lines for the alcohol sector (cultivation of sugarcane, sugar and alcohol and cogeneration), which had increased considerably at those years (BNDES, 2007).

In 1990, the context triggered the closure of IAA. After that, RIDESA was initially established through an agreement established between seven federal universities that were located in areas of activity of coordinating Planalsucar (Fonseca et al, 2007). In this way, it absorbed all the research work performed at that time by Planalsucar, incorporating the staff and infrastructure of the coordinating seats and experimental stations.

Their leadership proposed the creation of a plan that would include technological challenges related to new agricultural problems, industrial efficiency, awareness of the society towards the environment and technological advancements in all stages of ethanol production. To make it possible, financial resources from both government and private enterprise were demanded. After incorporates three more universities, RIDESA continued to research into new varieties of cane, expanding the program to meet the growing demand in the sector (UFSCar, 2010). In recent years, it has been constantly renovated, with a growing number of partner companies.

During the 1990s, Copersucar suffered a strong financial crisis due to strong fluctuations in the prices of sugar and alcohol in the international market. Furtado et al. (2008) reported the lack of interest of members to continue funding the CTC, which reduced the membership from 70 plants to less than 40 in the late 90's. Moreover, technologies developed by CTC, though extremely important to ensure profitability and the gradual increase of productivity, could be easily reproduced and appropriated by non-members. There was a feeling of uncertainty about the future of CTC.

Evolution of technological capabilities: 1990-2009. During this period, the survey of sugarcane was synthesized in R&D programs of institutions (RIDESA, IAC and CTC), who dedicated efforts directed particularly to the agricultural stage of the technological route of ethanol. Despite the downturn in the sector between 1990 and 2002, RIDESA continued research into new

varieties of sugarcane. During this period, the efforts of R&D network of universities resulted in the release of new varieties of sugarcane to the ethanol industry, or the technological R&D, developed in RIDESA constitute new innovations to market, qualified as Level 4 (Advanced Innovative). The accumulation of innovative capabilities through R&D of transgenic varieties in RIDESA result in new innovations to the world, qualified at Level 5 (Innovative global).

After the transition of the technology center for the sector in 2004, CTC (2010) reports the R&D that resulted in the release of 20 new varieties of sugarcane, new innovations to market, qualified at Level 4 (Advanced Innovative). Thus, investments in the breeding program over the past few years have resulted in more productive varieties, more resistant and adapted mainly due to the efforts of R&D conducted by researchers at the CTC.

Since 1990, the IAC has adopted new strategies to study for the breeding program of sugarcane. The knowledge accumulated in the IAC created new innovations to market, qualified at Level 4 (Advanced Innovative). For example, in 2007 four new varieties of sugarcane were offered to the sugarcane sector by IAC program (IAC, 2010). These varieties were selected with characteristics of high agricultural production, high sucrose and adaptable to mechanical harvest, thus contributing to reducing environmental impacts. Accordingly, these four varieties have been developed for mechanical harvesting, replacing the burning of sugarcane, often used in manual harvesting. That is, these are new innovations to market, classified at Level 4 (Advanced Innovative).

In recent years, the accumulation of technological innovation capabilities through the acquisition of knowledge with research in biotechnology contributed to the creation of two new biotech startups, Alellyx and CanaVialis. These companies carried out Level 5 R&D directed to applications of biotechnology, especially the improvement program of varieties with transgenic technique by which genes are inserted into the genome of different individuals of the cane (BNDES & CGEE, 2008).

With regard to the accumulation of technological capabilities in the industrial area, between 1986 and 2002, with the end of the Alcohol Program and the liberalization of the sector, the sector's companies faced a period of stagnation in the path of accumulation of technological capabilities. However, the technologies for producing ethanol from 1st generation in operation continued to suffer minor incremental adaptations through engineering activities to adapt and improve production processes and equipment systems, continuing the activities initiated in previous phase (Dantas & Figueiredo, 2009). These innovations represent incremental changes to the new company, classified at Level 3 (Intermediate Innovator). Despite the stagnation of the sector, some activities based on R&D companies introduced new technologies in the industry, constituting technological capacities for innovation Level 4 (Advanced Innovative).

Later, between 2003 and 2010, companies were concerned about the future of CTC due to financial crisis and transition experienced by this technology center. In this sense, large companies established internal domestic technology centers to accumulate new technological capabilities through strategic partnerships with suppliers, companies and institutes of technology in Brazil and abroad.

Conclusions and Implications

The evidence presented in this study shows that companies in the ethanol industry used at first a follower technology strategy ("catching up") toward the international border. This process is aligned to the reasoning described by Hobday (1995) and Kim (1997), where firms situated in developing countries acquire, for local operations at first, foreign technological capabilities. This strategy is also aligned to the prospect of Figueiredo (2009), i.e., the ethanol industry has accumulated technological capabilities, moving ("catching up") through a path of accumulation of production capacity and innovation, reaching companies earlier positioned at the international technological frontier.

Nonetheless, the Brazilian ethanol industry caused a qualitative shift in the very first stages of its career, accumulating innovative capabilities. In other words, it tracked a motion "path-creating catch-up". In the initial stage of developing, the industry activated qualitative difference in their technological trajectory (path-creating catching-up: stage A -> Stage B -> Stage C' -> Stage D'), which is aligned to the findings identified in the studies of Lee and Lim (2001) and Figueiredo (2010).

With regard to the accumulation of industrial technological capabilities, the Brazilian ethanol industry incorporated, initially, technological and managerial capabilities to use and operate import mature technologies to produce ethanol, classified as Level 1 (Production). Besides that, these companies continued the movement of "path-creating catching-up" toward the international border with the capacity development of Level 2 (Innovative Basic) and Level 3 (Intermediate Innovator), by means of engineering efforts to adapt and improve production processes and equipment systems. Later, during the regime of open economy (1990-2009), companies, institutes of technology and universities of the ethanol industry continued to acquire knowledge, which supported the movement of "path-creating catching-up", pushing the international border through R&D activities.

With regard to the accumulation of agricultural technological capabilities (raw materials), during the regime of import substitution industrialization, the technological capabilities of R&D were distributed among companies and institutions, such as Planalsucar, CTC and IAC. Therefore, these institutions, in partnership with companies of the sector, developed technological capabilities and shared innovation, classified as Level 3 (innovative Intermediate) and Level 4 (Advanced Innovative). In the following period, during the regime of open economy, after the ethanol sector deregulation, companies, research institutes and universities engaged themselves into R&D projects, developing new innovative technologies, qualified as Level 5 (Global Innovator). The establishment of partnerships between knowledge-based institutions could result in new settings and complementarities, what could enable reduced costs of research and development.

The process of technological accumulation in ethanol companies, in Brazil, however, presents some peculiarities in relation to the research approach of the technological accumulation of capabilities within firms in developing countries (Hobday, 1995; Kim, 1997; Lee & Lim, 2001; Figueiredo, 2003; 2008; 2009; 2010). That is, the companies used a uniform set of decentralized R&D in partnership with institutions, namely, research institutes and universities. In this

arrangement, the technological capabilities of R&D were distributed among companies and institutions, such as Planalsucar, Ridesa, CTC and IAC, which accumulated production, and later, innovative technological capabilities.

Besides these, the favorable market conditions, the wide availability of sugarcane and the flexibility of ethanol production, contributed to the accommodation of the ethanol industry. It resulted in stagnation of the accumulation process of technological capabilities for innovation. These factors led the sector to accumulate technological capabilities of production and innovation, which led to the imprisonment ("locked-in") of Brazilian ethanol in the technological trajectory to produce ethanol from 1st generation.

Nevertheless, empirical evidence concludes that macro-institutions, meso institutions, research institutes and universities played a key role on the path of accumulation of technological capabilities for production and innovation in the industry of Brazilian ethanol.

The results obtained by examining the relationship of the variables analyzed in this paper allow us to go beyond our understanding of the complexity of the process of accumulation of technological capabilities embedded in industries in emerging economies, specifically in the Brazilian ethanol. Evidence of this work indicates a set of future implications for public policies and business strategies of Brazilian ethanol. In this sense, the study points to some vulnerabilities in Brazilian ethanol industry regarding their ability to sustain their innovation performance, which implies changes in public policies and business strategies of the sector, focused on ethanol production 1st generation.

With respect to practical implications for public policy related to Brazilian ethanol, the evidence of this study proposes the establishment of representative government policies in line with demands and needs of the Brazilian ethanol industry. The nature of these policies should not only be concerned with the provision of resources, but also with the establishment of mechanism integrators of innovative activities carried out in universities, research institutes and leading companies in the Brazilian ethanol industry. This would avoid duplication of efforts and also the lack of integration between the accumulation process of innovative capabilities of knowledge-based institutions and Brazilian ethanol companies.

In this sense, government representatives can encourage the expansion of public policies for development of innovative technological capabilities within firms and also the establishment of links with suppliers and other sectors companies. This may stimulate the formation of innovative products that could spawn wealth for Brazilian ethanol companies. Therefore, new policies can target R&D within firms, in order to develop new products in partnership with companies from other industries, promoting diversification into new sectors and business lines, such as chemical, pharmaceutical and biotechnological industries.

Moreover, public policies of the Brazilian ethanol industry must redirect the strategies of accumulation of innovative capabilities, strongly linked to the accumulation trajectories of technological capabilities to produce ethanol from first generation. The continuity of innovation strategies in these existing paths will not promote the expansion of innovative capabilities in this sector. Public policies could create mechanisms and incentives to increase the accumulation of

technological capabilities of production and innovation in emerging route to produce ethanol from second generation, which is in the experimental level, being largely independently developed within research institutes and universities.

Regarding the implications for business strategies, the ethanol industry needs to deepen and sustain the acquisition of innovative capabilities, qualified at level 4 and level 5. More specifically, the innovative capabilities of this sector were accumulated largely within knowledge-based institutions. Companies in the ethanol industry should establish active relationships with these institutions in order to transform inventions produced in universities and research institutes, in innovations disseminated on an industrial scale.

Furthermore, the concentration of innovative activities within universities and research institutes decreased over the last few years the strategic importance of the companies in the process of accumulation of technological capabilities for innovation. Therefore, the evidence of this article suggest a reformulation of business strategies in order to expand the innovative activities of companies within the ethanol industry, which could result in the creation of innovations in industrial scale, diversification into other sectors and generating wealth for companies of Brazilian ethanol.

Finally, the evidence of this study encourage companies to structure internal areas of R&D, hire people responsible for the coordination of innovative activities and integrate innovative efforts carried out in institutions based on knowledge, suppliers and other sectors, such as industry chemical and pharmaceutical industry. Thus, companies in the ethanol industry should take a proactive behavior, through the direction of research and development in order to coordinate these efforts toward issues and future challenges to be faced in the context of major companies.

This study shows that institutions contribute partially for the explanation of the accumulation process technology in enterprises in developing countries, for example, ethanol Brazilian companies. Therefore, the various institutional mechanisms described in this study complement the mechanisms of intra and inter organizational learning, used by companies in developing countries, to explain the process of accumulation from an initial stock of knowledge to innovative technological capabilities.

Moreover, the institutional perspective also adds knowledge to the strategic management literature, specifically on capacity building and strategic skills (core capabilities or core competencies), for companies located on international technological border of developed countries (Porter, 1980;1985). The evidence presented in this article demonstrate the importance of institutions in the most basic stages of the technological trajectory, which further underpin the process of accumulation of essential strategic capabilities, more advanced and innovative. We add the institutional factors to the relationship of organizational factors, managerial, strategic, technological and learning processes within and between organizations to understand the process of technological accumulation into Brazil ethanol industry.

References

Ariffin, N., & Figueiredo, P. (2004). Internationalization of Innovative Capabilities: Counter evidence from the Eletronics Industry in Malaysia and Brasil. *Oxford Development Studies*, 32(4).

Bacha, C., & Shikida, P. (1999). Evolução da Agroindústria Canavieira Brasileira de 1975 a 1995. *Revista Brasileira de Economia*, 53(1), 69-90.

Bell, M., & Pavitt, K. (1993). Technological accumulation and industrial growth: contrasts between developed and developing countries. *Industrial and corporate change*, 2(2), 157-211.

Bell, M., & Figueiredo, P. (2010). *Building Innovative Capabilities in Latecomer Firms: Some Key Issues*. Versão rascunho.

BNDES e CGEE. *Bioetanol de Cana-de-açúcar. Energia para o Desenvolvimento Sustentável. Rio de Janeiro, novembro de 2008*. Disponível em: <http://www.sugarcanebioethanol.org/pt/download/etanol.pdf>. Acesso em: 10 de outubro de 2009.

BNDES. Banco Nacional de Desenvolvimento Econômico e Social. (2007). *Carteira do BNDES para setor de açúcar e álcool já soma R$ 19,7 bilhões*. Disponível em: <http://www.bndes.gov.br/SiteBNDES/bndes/bndes_pt/Institucional/Sala_de_Imprensa/Noticias/2007/20071203_not271_07.html>. Acesso em: 19 de janeiro de 2011.

CGEE. Centro de Gestão e Estudos Estratégicos. (2009). *Bioetanol combustível: uma oportunidade para o Brasil.*

CGEE. Centro de Gestão e Estudos Estratégicos. (2010). *Biocombustíveis aeronáuticos. Progressos e desafios*.

Coelho, S.; Lora, B., & Guardabassi, P. (2010). Aspectos ambientais da cadeia do etanol de cana-de-açúcar no estado de São Paulo. In: CORTEZ, Luís Augusto Barbosa. *Bioetanol de cana-de-açúcar: P&D para produtividade e sustentabilidade*. São Paulo: Blucher.

COPERSUCAR. Cooperativa de Produtores de Cana-de-Açúcar, Açúcar e Álcool do Estado de São Paulo. (2009). *Relatório de Gestão. Coopersucar 50 anos*. Disponível em: <http://www.copersucar.com.br>. Acesso em: 11 de outubro de 2010.

CTC. Centro de Tecnologia Canavieira. (2010). *Relatório de Realizações 2005-2010*.

Dantas, Eva, & Figueiredo, Paulo. (2009). *The Evolution of the Knowledge Accumulation Function in the Formation of the Brazilian Biofuels Innovation System*. VII GLOBELICS Conference in Dakar. Disponível em: <http://globelics2009dakar.merit.unu.edu/papers/1238516980_ED.pdf>. Acesso em: 09 de fevereiro de 2010.

DEDINI. Dedini Indústrias de Base. USD – Usina Sustentável Dedini.

Dimaggio, P., & Powell, W. (1983). The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. *American Sociological Review*, 48, 147 160.

Evans, P. (1995). *Embedded Autonomy. States and Industrial Transformation*. Estados Unidos da América: Princeton University Press.

Figueiredo, P. N. (2003). Learning, capability accumulation and firms differences: Evidence from latecomer steeel. *Industrial and Corporate Change*.

Figueiredo, P. N. (2009). *Gestão da Inovação. Conceitos, Métricas e Experiências de Empresas no Brasil.* Rio de Janeiro: LTC.

Figueiredo, P. N. (2010). Discontinuous innovation capability accumulation in latecomer natural resource-processing firms. *Technological Forecasting & Social Change*.

Fonseca, Maria. Da G. D., Silveira, J. M. J., Costa, C. M., Rosário, F. J. P., & Neves, R. E. (2007). *A dinâmica agroindustrial e tecnológica da agroindústria brasileira sob a ótica de sistemas de inovação: grãos e cana-de-açúcar*. Workshop BRICS.

Fonseca, M. S. (2008). *Acumulação de Capacidades Tecnológicas e Aprimoramento de Performance Operacional sob Diferentes Regimes Industriais: Evidências em Nível de Empresa da Indústria Química no Brasil (1950-2007).*

Furtado, A., Cortez, L., & Scandiffio, M. (2008). *O Sistema de Inovação da Agroindústria Canavieira Brasileira*. UNICAMP.

Hobday, M. (1995). *Innovation in East Asia. The Challenge to Japan*. Cheltenham: Edward Elgar Publishing Limite.

IAC. Instituto Agronômico de Campinas. Disponível em: <http://www.iac.sp.gov.br>. Acesso em: 25 de julho de 2010.

IEA BIOENERGY. International Energy Agency Bioenergy. (2009). *Bioenergy - A Sustainable and Reliable Energy Source. A review of status and prospects*. Disponível em: <http://www.ieabioenergy.com/LibItem.aspx?id=6479>. Acesso em: 23 de outubro de 2010.

Kim, L. (1997). Analytical Frameworks. In: Kim, L. *Imitation to Innovation*. Boston: Harvard Business School Press, 85-103.

Lall, S. (1992). Technological capabilities and industrialization. *Word Development*, 2(20), 165 186.

Lee, K., & Lim, C. (2001). Technological regimes, catching-up and leapfrogging: findings from the Korean industries. *Research Policy*, v. 30, 459-483.

Miranda, E. C. & Figueiredo, P. (2010). Dinâmica da acumulação de capacidades inovadoras: evidências de empresas de software no Rio de Janeiro e em São Paulo. *RAE*, 1(50).

Murmann, J. (2003). Knowledge and Competitive Advantage. The coevolution of Firms, Technology, and National Institutions. Inglaterra: Cambridge University Press.

Nelson, R., & Sampat B. (2001). Making sense of institutions as a factor shaping economic performance. *Journal of Economic Behavior & Organization*, v. 44, 31-54.

Nelson, R. (2008). What enables rapid economic progress: What are the needed institutions? *Research Policy*, v. 37, 1–11.

North, D. (1990). *Institutions, Institutional Change and Economic Performance*. New York: Cambridge University Press.

OECD, EUROSTAT, & FINEP. (1997). *Manual de Oslo. Diretrizes para coleta e interpretação de dados sobre inovação.* Tradução: FINEP - Financiadora de Estudos e Projetos, 3ª. ed.

Peng, M., Wang, D., Jiang, Y. (2008). An institution-based view of international business strategy: a focus on emerging economies. Journal of International Business Studies, v. 39, 920-936.

Porter, M. (1980). *Competitive strategy: techniques for analyzing industries and competitors*. New York: Free Press.

Porter, M. (1985) *Competitive advantage: creating and sustaining superior performance*. New York: Free Press.

REVISTA PESQUISA FAPESP. (2010). *O saldo de uma década. Como o Programa Genoma FAPESP criou novos paradigmas no ambiente de pesquisa brasileiro*. Ed. 174. Disponível em: <http://revistapesquisa.fapesp.br/?ed=936&lg=>. Acesso em: 26 de outubro de 2010.

RIDESA. Rede Interuniversitária de Desenvolvimento do Setor Sucroalcooleiro. (2010). *Catálogo Nacional de Variedades "RB" de Cana-de-Açúcar*.

UFSCAR. Universidade Federal de São Carlos. Centro de Ciências Agrárias. (2010). *Programa de Melhoramento Genético da Cana-de-Açúcar*. Disponível em: <http://pmgca.dbv.cca.ufscar.br>. Acesso em: 18 de julho de 2010.

Vedovello, C. (1997). Science parks and university-industry interaction: Geographical proximity between the agents as a driving force. *Technovation*, 4(17), 491-502.