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The Evolution of the Knowledge Accumulation Function in the Formation of the Brazilian Biofuels Innovation System

Eva Dantas[1]
Paulo Figueiredo[2]

Abstract

The analytical focus of research on innovation systems has been shifting recently to functions or processes that should be present in a well functioning innovation system and the dynamics of these systems. Yet, thus far, the conceptual analysis of functional dynamics and existing empirical studies reflect the realities of developed countries. Additional research is necessary to examine empirically the formation of technological innovation systems, specially 'new-to-the-world' innovation systems in a late industrialising context, and specifically how the knowledge accumulation function evolves in such systems. This paper is concerned with those issues: the formation of a 'new-to-the-world' technological innovation system in a late industrialising context, namely the Brazilian biofuels innovation system. It focuses, in particular, on the evolution of the knowledge accumulation function in the formation of such innovation system from 1975 to the present.

Keywords: technological innovation systems, knowledge accumulation function, late industrialisation

[1] German Development Institute (DIE), eva.dantas@die-gdi.de
[2] Getulio Vargas Foundation (FGV), pnf@fgv.br

1. Introduction

Over recent years, the analytical focus of research on innovation systems has been shifting away from structural analysis. Central to the new directions of research are the new inter-related focuses on functions or processes that should be present in a well functioning innovation system and the dynamics of these systems.

The functional approaches being developed in the context of the innovation system literature focus on sets of processes and activities, also labelled ‘functions’ of innovation systems – instead of only on structural components – that are believed to contribute to the generation, diffusion and use of innovations (Johnson, 2001; Bergek, Jacobsson et al, 2008). There are two main arguments underpinning the rationale for a functional analysis of innovation systems. First, some authors argue that a structural analysis of components and interactions cannot fully explain system performance (e.g. Jacobsson, 2008). This is because there are no ways to systematically evaluate the quality of components and interactions in systems (p.5). Hence, an additional analysis of the system ‘functioning’ – i.e. what actually is going on and being accomplished in the system – is necessary as an intermediate explanatory mechanism between system structure and performance (p.5). Second, other authors note that organisations tend to perform increasingly multiple functions in the system, thus an organisation-driven analysis that only lists the types of organizations that make up an innovation system remain limited (Galli and Teubal, 1997:346).

In the wake of growing interest in system functioning, several approaches to functional analysis have been developed. One perspective draws on the principles of evolutionary theory to propose the three main functions, which correspond to those principles, that should exist in an innovation system: the ‘generation of novelty leading to diversity’, ‘retention and transmission of information', and 'selection among alternatives' (McKelvey, 1997). A second approach differentiates between 'hard' and 'soft' functions (Galli and Teubal 1997). The main 'hard' functions include R&D and technical services. Whereas 'soft' functions comprise policy-making, diffusion of information, knowledge and technology, design and implementation of institutions and other catalytic roles. A third approach that has become increasingly diffused intends to draw a composite synthesis of insights about functions and processes found in the different innovation system perspectives (Johnson, 2001; Edquist, 2005; Hekkert, Suurs et al, 2007; Bergek, Jacobsson et al, 2008). Various slightly different synthesis have been suggested, but the recurring functions include, for instance: knowledge development and diffusion, market formation, entrepreneurship, legitimation, resource mobilisation and influencing the direction of search (Edquist 2005; Hekkert, Suurs et al. 2007; Bergek, Jacobsson et al. 2008).

Additionally, these functional approaches are not interested only in the analysis of functional patterns at a given time. Cutting across all these approaches to systemic functions is the preoccupation with further understanding system dynamics. Part of the effort to trace system dynamics, including the evolution of existing systems and emergence of new systems, consists of examining the emergence of key functions, for instance, knowledge development and entrepreneurial experimentation, and observing their transformation through time (cf. Alkemade, Kleinschmidt et al, 2007). Furthermore, within those studies emphasis has been given to the types of 'inducement' (e.g. R&D policy) and 'blocking' (e.g. poor articulation of demand) mechanisms driving and explaining functional dynamics (see Bergek, Jacobsson et al. 2008). In particular, the analysis of functional dynamics has been interested on the ways that new technological systems, mainly low carbon innovation systems emerge and develop in industrialised countries (e.g. Negro and Hekkert 2006; Suurs and Hekkert 2007; Jacobsson 2008; Negro, Suurs et al. 2008).

However, thus far, conceptual analysis on processes and functional dynamics reflects the realities of industrialised countries and existing empirical studies also focus on the experiences of the latter. There is an absence of systematic studies examining empirically the emergence and development of sectoral innovation systems - specially low carbon technological innovation systems – as well as systems functions or processes in late industrialising countries, and the main inducing and blocking mechanisms triggering their origin and transformation. In late industrialising contexts the main questions about system and functional dynamics are related to how systems and core systemic processes emerge and develop under very different starting conditions from those prevailing in developed countries, such as in available levels of capabilities of existing organisations.

This paper aims to contribute in that direction. It is concerned with formation of a low carbon technological innovation system in a late industrialising context, namely the Brazilian biofuels innovation system. It focuses, in particular, on the evolution of the knowledge accumulation function in the formation of system.

The empirical study follows a case study strategy and analyses the evolution of the knowledge accumulation function in the formation of the Brazilian biofuels innovation system from 1975 to the present. The preliminary findings of the study indicate that evolution of the knowledge accumulation function in the formation of the Brazilian biofuels innovation system involved initially the implementation of a mature simple technology followed by incremental changes upon this technology and at a later stage by the generation of novel knowledge and applications within an existing technological trajectory. Presently, the knowledge accumulation function is undergoing a major transition characterised by the creation of variety of technological alternatives and multiple directions of search towards new technological trajectories.

This paper is organised as follows. Section 2 proposes an analytical framework to examine the evolution of the knowledge accumulation function in the formation of a technological innovation system in a late industrialising context. Section 3 describes briefly the research method, whereas Sections 4 provides an overview of the industry background. Section 5 contains the analysis of the preliminary empirical evidence and Section 6 draws brief conclusions.

2. Analytical framework

Drawing on the literature of system functions (e.g. Bergek, Jacobsson et al, 2008:2 Jacobsson, 2008:6), it is proposed here that a technological innovation system is characterised by a set of core processes (or functions) that influence the performance of the system in terms of the generation, distribution and use of knowledge. Here we focus on one sub-set of these core processes, which is at the heart of innovation system (Jacobsson, 2008:6), namely the *knowledge accumulation function*.

We define the *knowledge accumulation function* very broadly – following a large body of literature on innovation and learning activities in both developing and developed countries[3] – to include the processes involved in the acquisition, implementation, use, operation, assimilation, diffusion, adaptation, change, and recombination of available knowledge, as well as the generation of novel disembodied or embodied knowledge. In other words, that includes not only knowledge-production through formalised R&D and design activities, but also experience-based knowledge producing processes.[4] We understand the evolution of the

[3] For examples, see Hobday, 1995; Kim, 1980; Kim, 1997; Figueiredo, 2001; Lall, 1992; Bell and Pavitt, 1995; Dosi, 1982; Lundvall, 2007; etc.
[4] This is line with Lundval (2007). He refers to these two types of processes as the 'Science, Technology and Innovation mode' (STI mode) and the 'Doing, Using and Interacting' (DUI mode) and stresses the important contribution of both sets of processes in the overall innovation processes.

knowledge accumulation function in the formation of the technological innovation system as the initiation, establishment and functioning of different knowledge accumulation processes and the implementation of technological changes in an emerging technological innovation system and the transformations the undergo through time.

The framework used in the study for the assessment of the evolution of the *knowledge accumulation function* draws on a number of inter-related bodies of literature which highlight diverse features of learning and innovation in firms, sectors and countries at differing distances from the international innovation frontier. This includes on the one hand, streams of literature concerned with on innovation life cycle and innovation patterns in the evolution of new sectors in industrialised countries (e.g. Utterback and Abernathy, 1975, etc) and capability and innovation also in a context of industrialised countries (e.g. Teece, Pisano et al, 1991; Granstrand, Patel et al, 1997; Coombs and Metcalfe, 2000). On the other hand, it derives guidance from the accumulation of capabilities and catching up processes in developing countries (e.g. Hobday, 1995; Kim, 1980; Kim, 1997; Figueiredo, 2001; Lall 1992; Lee, Bae et al, 1988; Lee and Lim, 2001; Kim and Lee, 1987), also specifically on reverse innovation life cycle approaches (Kim, 1997; Hobday 1995) and transition to leadership frameworks (Dutrénit, 2000; Hobday, Rush et al, 2004; Dantas 2006, etc.). But since the study is concerned with knowledge accumulation processes in the overall sectoral innovation system, it differs from these models in the sense that it includes in the analysis not only knowledge accumulation processes in firms, but also involving other types of organisations.

This framework distinguishes the knowledge accumulation function in terms of two dimensions. Taking the definition of “innovation” as a starting point in which innovation is understood as the commercial application of new technology in the economy, we argue that to understand the knowledge accumulation function, one dimension that is important refer to what types of technological changes are actually implemented in the production of goods and services in the system. Drawing on literature on learning and innovation in developing countries (see above) we identify the following processes: i) the selection, implementation, and troubleshooting of existing product and process technologies; ii) the adaptation and improvements in existing technologies; iii) the introduction of new technologies within existing technological trajectories; and iv) the introduction of new technologies along new technological trajectories. However, by looking only at the technological changes that are implemented operationally, we may ignore a vast spectrum of processes that also contribute to the knowledge accumulation function. Presumably not all knowledge producing activities in the system will lead to new technologies being introduced operationally in the system – at least not without a time lag – and those technological changes will be the outcome of only a fraction of those activities. For instance, not all research activities will lead to the introduction of new technologies commercially. We argue that in order to understand the knowledge accumulation function, it would be illuminating to examine the encompassing knowledge producing activities in the system. This involve: i) operating and production activities; ii) engineering and design activities; iii) research and technological development activities within a technological trajectory; and iv) research and technological development in diverse technological trajectories.

3. Research method

This research requires empirical understanding of the evolution of the knowledge accumulation function in the formation of technological innovation systems in a late industrialising country. This includes the analysis of the emergence and transformation through time of the different knowledge accumulation processes and the types of technological changes implemented in the system.

In order to examine those issues, the empirical study consists of a case study of the Brazilian biofuels innovation system from 1975 to the present. The main rationale for choosing the Brazilian biofuels innovation system in this research is related to the exceptionality of its formation pattern. Whereas in advanced industrialised economies, the emergence of new-to-the-world sectoral innovation systems is common, the most widespread phenomenon in developing countries is the emergence and development of sectoral innovation systems with a considerable lag in relation to industrialised countries (Jacobsson, 2005; Jacobsson and Bergek, 2006). The Brazilian biofuels innovation system is an exceptional case of emergence and development of a new-to-the-world sectoral innovation systems in a developing country context. Therefore, it would be interesting to known more about this latter formation pattern in late industrialising economies.

The focus of the study is the knowledge accumulation function in the biofuels innovation system as defined by the product group involving liquid biofuels for transport (e.g. ethanol, biodiesel, biokerosene, etc.) and the underlying relevant knowledge bases. Drawing on the literature on system functioning (e.g. Hekkert et al, 2007, etc), the centre of attention in this study is on mapping the main 'events' - here defined as the key knowledge producing processes and implementation of technological changes and their transformation in the system - in the evolution of the knowledge accumulation function. The focus is on these processes in the formation of the technological innovation system, rather than tracing them at the level of individual organisations.

Data collection relied on semi-structured interviews, informal meetings and documentation. The first round of data collection was carried out between November and December 2008; 60 interviews and in addition a number of informal meetings were carried out. The selection of interviewees and data gathering activities followed a purposeful sampling logic. Similarly to Cusmano et al (2008), the objective of the sampling was to obtain information about the prime trends in terms of knowledge accumulation processes at each stage, as contrasted to drawing a representative view of all such processes. With that purpose, sampling and data gathering activities moved from aggregate sectoral observations to identify the main sequence of events in the evolution of the knowledge accumulation function to micro-level observations to acquire additional details about the main events identified in the former type of data gathering activities. The following steps were involved. First, drawing on existing publications and network of contacts a number of key informants were identified and interviewed who could provide information on the main sequence of knowledge accumulation events at different time periods in the formation of the innovation system and the actors which had been central in those events. Second, additional informal meetings were organised for snowballing purposes to identify key informants and organisations and obtain research access to these information sources. Third, interviews with informants identified in the first and second steps were carried out. These included informants from biofuel mills, capital goods manufacturers, engineering and service firms, other relevant knowledge-producing organisations (e.g. research institutes, universities, bridging organisations). These interviews covered two sorts of issues: i) the main events in the evolution of the knowledge accumulation function in the system, and ii) the involvement of the individual organisation being interviewed in those events. Fourth, documentation including companies reports, sectoral publications, press articles, and other studies were obtained from interviewees and through further research. These sources of information helped to corroborate observations from interviews and obtain additional detailed information about the key knowledge accumulation events.

4. Empirical context: A brief overview of Brazil’s Biofuels Industry

Brazil is the world leader in the use of biofuels for transport, particularly ethanol. In 2005, sugar cane ethanol supplied 14.5 percent of the energy for land transportation (excluding railroads) and 31.3 percent of the total liquid fuel energy consumption for engines. In the United States, this corresponded to 2.5 percent in 2004. Brazil was the world's leading producer of ethanol until 2004, contributing slightly less than half the world's total, followed by the United States. Since 2005, the United States has slightly surpassed Brazil’s production. Together these two countries produce 70 percent of the world’s ethanol production. The European Union, with a production of almost 0.5 million tons, is estimated to have produced about 10% of the world's total ethanol. Brazil is still the largest exporter of ethanol and production costs are the lowest in the world. In addition to lower production costs, Brazil has another important advantage. In Central-South Brazil only 1 unit of fossil energy is used for each 8-9 units of energy produced of ethanol from sugarcane; for corn ethanol in the United States, for example, this ratio is around 1.8.

Sugar cane was introduced in Brazil in 1532. In the last century, new varieties of sugar cane that could increase the amount of sucrose produced per hectare have been introduced. Today about 50% of the sucrose of sugar cane produced in the country is directed to the production of sugar while the other half is used to produce ethanol, which is made with part of the extracted juice and the molasses resulting from the manufacture of the sugar. Within the Brazilian context, the State of São Paulo emerges as a focal point for production. Currently, 62% of the Brazilian ethanol production (based on sugar cane) is concentrated in the state of São Paulo.

5. Empirical findings

In the next sub-sections, we provide some preliminary evidence on the evolution of the knowledge accumulation function in the formation of the Brazilian biofuels innovation system between 1975 to the present. Section 5.1 covers the period of establishment and first stage of the Brazilian National Alcohol Programme (Proálcool) from 1975 to 1978. The second period from 1979 to 1985 involving the consolidation of the National Alcohol Programme is addressed in Section 5.2. Section 5.3 examines the period from 1986 and 2002. This phase started with the collapse of oil prices in 1986 and is followed by the stagnation of the National Alcohol Programme subsequently. Section 5.3 corresponds to the period from 2003 to the present in which there has been a resurgence of ethanol production in Brazil.

5.1 From 1975 to 1978: formative phase

The formation of a biofuels innovation system in Brazil intensified following the establishment of the National Alcohol Programme in 1975. In terms of the knowledge accumulation function, the initial processes at this stage were centred on the adaptation of existing technologies through re-design and engineering activities. The use of ethanol as transport fuel had been shown to be technically viable since ethanol-run experiments with the Ford Model T in 1908. Besides, as emphasised by several respondents, by the mid 1970s, ethanol production technologies were mature and simple and involved well known fermentation and distillation processes. The implementation of the technology in the production of anhydrous ethanol by sugar mills to be blended with gasoline– which was the focus of the National Alcohol Programme during this phase – involved adaptations in processes to scale up production and the introduction of an extra stage of dehydration. This consisted, for instance, in re-designing chemical engineering processes to change fermentation and increase alcohol content.

Subsequently, continuous improvements in production technologies were introduced in all phases of the production process through design and engineering activities carried out by the equipment supply firms and R&D institutes. As asserted by an interviewee from a capital goods manufacturer,

> “the development of the technologies initially was based on incremental changes, more on trial and error, and tacit, rather than explicit knowledge and formal activities”.

The improvements involved small changes in equipment to solve bottlenecks identified during production, as well as changes to improve each stage of the production process, such as the preparation of the sugar cane for milling, improving milling and mill equipment to increase the quantity of sugar cane juice extracted.

In addition, another important component of the knowledge accumulation function during this phase was concerned with agricultural research and development activities. These R&D activities were concentrated a specific technological trajectory associated to sugar cane as feedstock for ethanol production and the associated agronomic practices. Two large sugar cane conventional improvement programmes were carried out for the development of new varieties. The National Programme for Sugar Cane Improvement (PLANALSUCAR) had been created in 1971 by the Sugar and Alcohol Institute (IAA). In the context of PLANALSUCAR, R&D activities focused on genetics, phytotechnology, entomology, plant breeding and aimed at producing novel high-yield and more resistant varieties. Another improvement programme was undertaken by the R&D centre of the Cooperative of Sugar

Cane, Sugar and Alcohol Producers of the State of São Paulo (COPERSUCAR), the COPERSUCAR Technology Centre (CTC). From the early 1970, the CTC also carried out studies of sugar cane cultivars and breeding activities.

5.2 From 1979 to 1985: growth phase

This period coincided with the expansion of the National Alcohol Programme, a marked increase in ethanol production and a new focus on the production of hydrous ethanol to be used in ethanol-only cars that were introduced in Brazil in the end of the 1970s. The main processes related to the implementation of technological changes in the production of ethanol continued to be centred on the introduction of successive improvements in production processes based on engineering and design activities. Engineers from the COPERSUCAR Technology Centre (CTC) worked together with the ethanol mills to identify bottlenecks in the production processes and facilities, develop improvements and subsequently transfer the new solutions to the companies. For instance, projects were undertaken to improve milling and fermentation processes. CTC also worked out with ethanol mills to systematise investment project procedures, and transfer of knowledge in basic engineering. Part of the efforts also drawn on the acquisition of foreign technologies and transfer to ethanol mills.

The agricultural R&D activities on sugar cane improvement carried out from the previous period onwards led during this time to the introduction of a stream of new sugar cane varieties and other agricultural technologies that contributed to increase sugar cane productivity. In 1981, CTC introduced the first new sugar cane varieties developed within its sugar cane improvement programme (named then SP varieties, now CTC varieties) and since then it has introduced on average two new varieties per year. Simultaneously, the PLANALSUCAR worked in the development of the RB varieties.

The boom in ethanol production was also followed by growing interest in exploring different technological development directions for ethanol and more generally biofuels production. Experimental work and R&D activities concerned with biofuels, but oriented to other technological trajectories beyond sugar cane and with variable outcomes started to emerge. A R&D project undertaken by the National Institute of Technology (INT) and the Brazilian oil company Petrobras concentrated on developing a cassava-based ethanol production process. Other efforts, involving INT and other actors such as the Institute of Technology Research (IPT) and the Federal University of Ceara (UFC), focused on the production of biodiesel from several oil species such as babassu, castor beans, peanut, soya, etc. Projects to develop a biojet fuel or biokerozene were also carried out by UFC, but discontinued by the mid 1980s. In addition, more fundamental research was initiated at Federal University of Rio de Janeiro (UFRJ), University of Sao Paulo (USP), INT and IPT on biotechnological processes with an interest to lead to waste biomass-based biofuels.

5.3 From 1986 to 2002: slow down phase

Following the Brazilian economic crisis from the early 1980s, the collapse of oil prices in 1986, increases in world sugar prices, and supply shortages, the National Alcohol Programme and the biofuels industry went through a major crisis. Subsidies to the sector were greatly reduced. These confluence of factors also led to slow paced investments on the knowledge accumulation activities and significant re-arrangements in those activities over the next decade and half.

The most widespread form of knowledge accumulation in terms of introduction of technologies into operational use continued to be adaptations based on engineering work as seen in the previous phase. However, during this period R&D-based efforts to introduce new technologies were also observable. An engineering company, Tecbio, developed and introduced from 2001 biodiesel industrial plants. The use of co-generation was implemented in ethanol mills from 1995. New fermentation processes were developed in partnership between Dedini and IPT. Whereas from the late 1990s, a new distillation technology was developed and implemented by UNICAMP and engineering and capital goods firms B&S and JW.

Although, there was a continuous pipeline for the introduction of superior sugar cane varieties and replacement of old ones as a result of agricultural R&D programmes, those programmes went through major readjustments. In 1990, the Sugar and Alcohol Institute (IAA) and National Programme for Sugar Cane Improvement (PLANALSUCAR) were extinguished. The experimental stations and other resources developed by the programme were subsequently integrated in a network of universities involved with sugar cane research and development, the Inter-University Network for the Development of the Sugar Cane Sector (RIDESA). A new sugar cane improvement programme, the Sugar Cane Genetic Improvement Programme (PMGCA) coordinated by one of the universities in the network, the Federal University of Sao Carlos (UFSCar) and partly funded by ethanol mills was initiated. During this period, the improvement programme of the COPERSUCAR Technology Centre (CTC) also limited its activities and closed experimental stations. However, a third improvement programme was created in 1994, the Sugar Cane Programme (PROCANA) of the Agronomic Institute of Campinas (IAC).

In the late 1990s, basic research activities still within the existing sugar cane technological trajectory were intensified. In 1998, The Sugar Cane Expressed Sequence Tags Project (SUCEST) was initiated to map sugar cane genes and analyse gene expression. From 2000, within the Sugarcane Signal Transduction Project (SUCAST) studies were carried out to identify and characterise functionally components that regulate plant cell behaviour, in this case of sugar cane.

New directions of research contributing to the search for new technological trajectories continued to develop slowly at a number of universities. This concentrated, for instance, on the studies of plant physiology and cellular wall structures, the fermentation of hemicellulose and from 2000, the development of technologies for use of lignocellulosic residues for the production of ethanol with emphasis on the development of pre-treatment processes (e.g. acid hydrolysis and enzymatic hydrolysis).

5.4 From 2003 to present: resurgence phase

In the early 2000s, growing concerns about climate change, energy security and increasing oil prices, coupled with the introduction of flex-fuel vehicles in Brazil has created the conditions for the resurgence and transformation of the ethanol and more broadly biofuels sector in Brazil.

A growing trend in the implementation of the technological changes operationally in the economy involved the acquisition by capital goods firms of foreign technologies, local production and introduction in ethanol mill operations, with adjustments carried out with ethanol mills during installation and commissioning. One such case is, for example, extraction technologies in which the former conventional milling technology has been replaced by the diffusion method. The diffuser technology has been developed by Bosch and is produced and supplied in Brazil by a domestic capital goods firm. The latter involves high initial investments and has not been widely adopted by ethanol mills. Other examples include the adoption of mollecular sieves developed by Katzen International and parallel axis reducers developed by Perkum, a German company, and biodiesel plants built through license from Austrian company.

Apart from the identifiable shift towards relying on the acquisition of foreign technologies to introduce technological changes in production, the approach of introducing changes based on design and engineering continues to be the cornerstone of the sector. The words of an interviewee from an engineering and capital goods firm captures the dynamics of the process:

> "in most developments, there is no R&D. It is development in engineering. There is already a technology and we just go on adapting it for new scales, and depending on the different regions, climate, soils, to the characteristics of the sugar cane. Research and development would only be necessary, if we would start working with other raw materials".

In this vein, a plethora of small changes, partly also based on formalised R&D activities have been introduced ranging from the introduction of water-producing ethanol plants, micro-ethanol mills, better co-generation technologies, i.e. better boilers, and changes in distillation equipment to increase volumes.

Further deepening of the sugar cane ethanol technological trajectory is resulted from publicly financed research projects, principally by the Sao Paulo State Funding Agency (FAPESP) on sugar cane genomics. The SUCEST and SUCAST projects are followed by the Project SUCEST-FUN from 2004 which is concerned with functional analysis of sugar cane genes and investigates the links between the genes mapped by the SUCEST project and desirable agronomic traits such as pest and drought resistance, sucrose content, and so on. In 2008, the

Biomass Project of the FAPESP-funded Bioenergy Programme (BIOEN) was initiated. The objectives of the project are to undertake basic research on sugar cane, (but also involving other plant feedstock) investigating broadly and systemically sugar cane biology.

But increasingly research and development efforts are being building up on multiple directions of search seeking to foster a variety of biofuels technological alternatives. An important line of effort is the search for alternative feedstocks for biodiesel production. This includes a multitude of oil seeds and non-food crops feedstock, residues, tallow, but also the start up of new projects on algae-based biodiesel, what has been labelled third generation biofuels. Further R&D activities are being undertaken on lignocellulosic ethanol production. Those include explorations in several different routes such as enzymatic, chemical and termo-chemical methods. Those projects are at different stages of development, mostly still on a research stage, but with some at pilot stage such as the lignocellulosic ethanol project being carried out by Petrobras and the Federal University of Rio de Janeiro (UFRJ) and the Dedini Rapid Hydrolyses Process which is in demonstration phase, though it has encountered technical difficulties. Another direction of search consists of the current development by the Brazilian engineering company Tecbio with Boeing and NASA of biokerozene, a hydrocarbon from residue and palm oil. Also entering the demonstration stage is the synthetic biology process developed by the Californian company Amyris for the production of biodiesel from sugar cane. Amyris in a joint venture with the Brazilian company Crystalsev are carrying out the scale up of the process in Brazil and installing in 2009 a demonstration plant in cooperation with Santelisa Vale, a Brazilian ethanol mill.

6. Conclusions

The objective of this paper was to explore the evolution of the knowledge accumulation function in the formation of technological innovation systems in late industrialising countries. Drawing on qualitative evidence, the paper examined the development of the knowledge accumulation function in terms of the forms of technological changes implemented operationally in the system and the types of knowledge producing activities carried out in the formation of the Brazilian biofuels innovation system from the mid 1970s onwards.

The preliminary evidence discussed in this paper indicates that the evolution of the knowledge accumulation function in the formation of a “new to the world” biofuels innovation system in in Brazil over the last three decades built upon adaptations and improvements on a well know simple technology. It started with the implementation in production of simple adaptations based on engineering and design activities. Over time it evolved to include the operational introduction of new technologies drawing on R&D activities within a very specific technological trajectory, that of sugar cane-based ethanol production. These were added by a massive research effort starting from the late 1990s on sugar cane genomics, but that have not led so far to commercial applications. Lately, some efforts have been carried out to introduce new technologies in other technological trajectories, such a biodiesel production and considerable research efforts are under way on the so-called second and third generation biofuels.

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