Industrial Development and the Innovation System of the Ethanol Sector in Brazil

INSTITUTE OF DEVELOPING ECONOMIES

Discussion Papers are preliminary materials circulated
to stimulate discussions and critical comments

DISCUSSION PAPER No. 109

Industrial Development and the Innovation System of the Ethanol Sector in Brazil

Yasushi Ueki *

June 2007

Abstract
The purpose of this paper is to analyze innovations and the innovation system and its dynamics in the ethanol sector in the State of São Paulo. More specifically, this paper focuses on the development process in the sector, the public policies taken to promote the sector, and the organizations and key players involved in these policies and their responses to unforeseeable changes in economic, social and technological environments. To this end, this paper takes an historical perspective and reviews data on the cultivation of sugar cane, the production of ethanol, and on sugar cane yields as indicators of the innovations achieved in the sector. The geographical distribution of these indicators is also examined. Next, several cases in Piracicaba and Campinas in the State of São Paulo are presented; these give us a more concrete idea of the processes involved in innovation and technology transfer. Based on these observations, the ethanol cluster and the innovation system of the State of São Paulo are discussed from the viewpoint of the flowchart approach to industrial cluster policy.

Keywords: Industrial Agglomeration, Innovation, Sugar Cane, Sugar, Ethanol, Brazil
JEL classification: Q16, Q42, R12

---

* Research Fellow, Development Studies Center, Institute of Developing Economies (IDE/JETRO). Correspondence Address: 3-2-2 Wakaba, Mihama-ku, Chiba-shi, Chiba 261-8545, JAPAN. Email: yasushi_ueki@ide.go.jp. Phone: +81-43-299-9641. Fax: +81-43-299-9763.

The Institute of Developing Economies (IDE) is a semigovernmental, nonpartisan, nonprofit research institute, founded in 1958. The Institute merged with the Japan External Trade Organization (JETRO) on July 1, 1998. The Institute conducts basic and comprehensive studies on economic and related affairs in all developing countries and regions, including Asia, the Middle East, Africa, Latin America, Oceania, and Eastern Europe.

INSTITUTE OF DEVELOPING ECONOMIES (IDE), JETRO
3-2-2, WAKABA, MIHAMA-KU, CHIBA-SHI
CHIBA 261-8545, JAPAN

Industrial Development and the Innovation System of the Ethanol Sector in Brazil*

Yasushi Ueki#

June 1, 2007

Abstract

The purpose of this paper is to analyze innovations and the innovation system and its dynamics in the ethanol sector in the State of São Paulo. More specifically, this paper focuses on the development process in the sector, the public policies taken to promote the sector, and the organizations and key players involved in these policies and their responses to unforeseeable changes in economic, social and technological environments. To this end, this paper takes an historical perspective and reviews data on the cultivation of sugar cane, the production of ethanol, and on sugar cane yields as indicators of the innovations achieved in the sector. The geographical distribution of these indicators is also examined. Next, several cases in Piracicaba and Campinas in the State of São Paulo are presented; these give us a more concrete idea of the processes involved in innovation and technology transfer. Based on these observations, the ethanol cluster and the innovation system of the State of São Paulo are discussed from the viewpoint of the flowchart approach to industrial cluster policy.

Keywords: Industrial Agglomeration, Innovation, Sugar Cane, Sugar, Ethanol, Brazil

JEL classification: Q16, Q42, R12

* I would like to express my gratitude to Antonio Botelho and Alex da Silva Alves of the Pontifical Catholic

University of Rio de Janeiro (PUC-RJ) and Yasushi Ninomiya and Elina Oshima of the Japan External Trade Organization (JETRO) São Paulo for their support in arranging interviews. All errors are mine.

Research Fellow, International Economics Studies Group, Development Studies Center, Institute of Developing Economies (IDE/JETRO). Correspondence Address: 3-2-2 Wakaba, Mihama-ku, Chiba-shi, Chiba 261-8545, JAPAN. Email: yasushi_ueki@ide.go.jp. Phone: +81-43-299-9641. Fax: +81-43-299-9763.

1. Introduction

The purpose of this paper is to analyze innovations and the innovation system and its dynamics in the ethanol sector in the State of São Paulo (SP). More specifically, this paper focuses on the development process in the sector, the public policies taken to promote the sector, the organizations and key players involved in the policies and their responses to unforeseeable changes in economic, social and technological environments. To this end, this paper takes an historical perspective and reviews data on the cultivation of sugar cane, the production of ethanol, and on sugar cane yields (tonnes of sugar cane per hectare [ha]) as indicators of innovations achieved in the sector. This report also observes cases in Piracicaba and Campinas in São Paulo State; these give us a more concrete idea of the processes involved in innovation and technology transfer.

Figure 1 depicts basic material flows during the process of sugar and ethanol production. The sugar and ethanol industry basically consists of the agricultural process to cultivate sugar cane and the industrial process to transform sugar cane as a raw material into ethanol. Generally, sugar cane is farmed on lands owned and rented by cane processing millers. Millers also buy sugar cane from farmers. Cane fields are located around the mills. The harvested canes are cleaned and crushed to obtain juice. The by-products of the cleaning and crushing processes, or "bagasse," are re-used as inputs to generate heat and electricity. Sugar is made from the juice. The juice and molasses that are generated through the production of sugar go into the processes of fermentation and distillation to obtain hydrated and anhydrous ethanol.

Figure 1: Sugar and Ethanol Production Chain

In order to improve efficiencies in sugar and ethanol production, it is necessary to enhance cane yields and the quality of cane agriculturally, and to develop new industrial processes, including those for re-using by-products. It is also very important to improve the industrial process by finding better yeast strains and by monitoring the fermentation process. For this reason, this paper introduces the current situation with regard to the development and transfer of agricultural and industrial technologies, including fermentation, together with the key institutions involved.

The outline of this paper is as follows. In Section 2, the supply and demand situation for ethanol is discussed. The nature of the geographical distribution of the sugar cane sector is described in Section 3. Section 4 presents case studies on the industrial cluster of sugar and ethanol production; this is agglomerated around Piracicaba and the innovation system centered on the State of São Paulo. Section 5 discusses the factors stimulating the formation and consolidation of the innovation system in the cane sector, and summarizes the innovation system of the region and the impact of developments in the innovative cane processing sector on other industrial sectors. Section 6 concludes the paper.

The author conducted a field survey in the State of São Paulo between November and December 2006. In order to identify the key parties involved in the state innovation system for the sector and to obtain information on the practices involved in promoting innovation and technology transfers, I interviewed persons from the academic sector, an industrial group, a producers' association, and private companies from the sugar and ethanol, plant engineering, commercial and consulting service sectors.

2. Development of the Ethanol Sector

2.1. Cultivation of Sugar Cane

The cultivation of sugar cane, a raw material for both sugar and ethanol, was introduced to Brazil by the Portuguese colonial government in the 16th century after their arrival in the year 1500. Since the founding of the nation, this sector, therefore, has been significant for Brazil. In 1961, the country was already the second largest sugar cane producer in the world and it produced more than 13 per cent of the world's sugar cane, following India who contributed about 25 per cent of the world's production. In 1980, Brazil overtook India as the world's largest sugar cane producer. Brazil's production accounted for more than 30 per cent of the world's total in 2005, according to FAOSTAT, a statistics database of the Food and Agriculture Organization of the United Nations (FAO). Even today, it is one of the fastest growing agricultural sectors in Brazil.

Historically, the expansion of sugar cane fields in Brazil was moderate until the middle of the 1970s, but in 1974 the area of sugar cane harvested reached two million hectares for the first time in Brazil's history, double the area of 1954. The thirteen years that followed were enough to increase this area to more than four million hectares. This upward trend dipped in 1987, and the area peaked out at 4.3 million hectares in that year before starting to decline to 3.9 million hectares in 1993. This trajectory was reversed in 1994 and growth accelerated remarkably in the 2000s. The area remained at over five million hectares and increased to 5.8 million hectares in 2005. The quantity of sugar cane production has experienced a similar trajectory to that for the area devoted to sugar cane fields.

Figure 2: Area of Sugar Cane Harvested (thousand ha: left axis) and Production (million tonnes: right axis) in Brazil for 1947-2005

2.2. National Policies for the Promotion of Sugar-Cane-based Ethanol Production

2.2.1. Historical Origins of the Policies taken from the 1970s

In the process of industrial development, the Brazilian government has been closely involved in the progress of the sector. The government has promoted the conversion of sugar cane into ethanol. As early as 1931, the government had already embarked on a policy to promote the production and consumption of ethanol derived from sugar cane by requiring a mixture of five per cent ethanol in imported gasoline.

The creation of the Sugar and Alcohol Institute (Instituto do Açúcar e do Álcool: IAA) in 1933 strengthened both the means the federal government had at its disposal to implement industrial policy and its ability to intervene in the sugar and ethanol sector.

The IAA set sugar production quotas and fixed prices. These government interventions remained until the 1990s. The IAA was also involved in programs to modernize the sector and to promote ethanol production to stimulate the rapid growth in the production of sugar cane and ethanol that was observed from the mid-1970s.

2.2.2. Modernization

According to Nunberg (1986), in the early 1970s, the IAA established financing systems to modernize the sector with the aims of (1) eliminating non-profitable mills and creating larger-scale centralized mills through mergers, incorporations, and relocations, (2) modernizing the remaining obsolete cane processing plants, and (3) implementing scientific research projects in the areas of genetics, entomology, and agronomy in order to breed new high-yield cane varieties. The IAA also used its financial resources to strengthen the infrastructure required by exporters.

Regarding the breeding of new cane varieties, the IAA implemented a national agricultural research program named the National Program of Sugar Cane Improvement (Programa Nacional de Melhoramento da Cana-de-açúcar: PLANALSUCAR). The innovation system for the development of new varieties, including PLANALSUCAR, will be discussed later.

2.2.3. National Alcohol Program (Programa Nacional do Álcool: PROALCOOL)

The federal government launched the PROALCOOL program in 1975 as part of its automobile fuel policy. Decree No. 76,593, dated November 14, 1975, declared that the production of ethanol derived from sugar cane, manioc or any another raw materials would be stimulated through an expansion in the supply of raw materials, with special emphasis being placed on an increase in agricultural production, the modernization and expansion of existing distilleries, and the installation of new production units.

However, the policy objectives were adjusted in accordance with the conditions of the sugar, ethanol, and international oil markets. The implementation period for the PROALCOOL program can largely be divided into two phases.

Phase I (1975-1979) was the initial phase. Its original objective was to convert excess sugar supply into anhydrous alcohol in response to a weak world sugar market. In this phase, anhydrous alcohol was in production in distilleries that were annexed to the sugar mills. PETROBRAS, a Brazilian oil company, blended ethanol in gasoline and distributed ethanol-blended gasoline for vehicle fuel. Phase II (1979-1985) is characterized as the expansion phase. Following the second oil crisis, the program put more emphasis on expanding the production of hydrous alcohol by using independent distilleries and ethanol. During this period, full ethanol-fueled vehicles were introduced to the domestic market.

2.2.4. Deregulation and Liberalization

During the 1985-1990s, this program was redefined. This came about because of the decline and subsequent stability of the international oil price, a shortage of ethanol (which was imported from 1989) together with a large surplus of gasoline, and mounting criticism for the heavy subsidies being given to inefficient ethanol producers.

In 1990, the IAA was abolished. The government deregulated prices of anhydrous ethanol in 1997, and of hydrous ethanol in 1999. Presently, the government controls only the ratio of ethanol that is to be blended into gasoline.

2.3. Factors affecting the Production and Consumption of Ethanol

PROALCOOL encouraged sugar producers to convert their sugar cane into ethanol, but the quantity of ethanol production remained at a level of less than 700 thousand cubic meters until 1976. In 1977, ethanol production more than doubled to reach 1,300 thousand cubic meters from 642 thousand cubic meters in 1976, according to statistics of the Brazilian Energy Balance (Balanço Energético Nacional: BEN) presented by the Ministry of Mines and Energy (Ministério de Minas e Energia: MME). Nevertheless, the business climate for the ethanol sector was able to be influenced not only by public policy focused on the sector but also by other factors. The observations below show that, following PROALCOOL's campaign to boost sugar cane cultivation, inflated oil prices and the introduction of ethanol-fueled cars produced an explosion both in the production of ethanol and in demand.

2.3.1. Conditions of the Oil Market

The effects of the second oil crisis are quite evident. Around 1979, when the oil crisis happened, gasoline prices in Brazil soared from 419 dollars per cubic meter in 1978 to 673 dollars in 1982. Prices returned to lower levels before the second oil crisis in 1985 when prices went down to 396 dollars. During this period, between 1978 and 1985, the quantity of ethanol production increased from 2,248 thousand cubic meters in

1978 to 11,563 in 1985. In the period after 2003, when oil prices rushed to a record level after the Iraq war in 2003 and there was increased global demand for oil, ethanol production increased from 12.6 million cubic meters in 2002 to 16.0 million in 2005. But to give a convincing explanation for the continuous growth in ethanol consumption after 2003 mention must be made of the commercialization of flex-fueled vehicles (FFVs).

Figure 3: The Production, Consumption and Net Exports of Ethanol for 1970-2005 (1,000 m^3: left axis) and Price Ratios for 1979-2005 (Gasoline/Ethanol: Right Axis) in Brazil

2.3.2. Innovations in the Automobile Sector

In reality, behind these trends in ethanol production is the introduction of ethanol-fueled vehicles and the innovations in the same. This also had a significant effect on demand for ethanol, which would be consumed as an alternative energy to gasoline. Although there were only 4,624 ethanol vehicles produced and 3,120 units sold in 1979 when the first ethanol fueled cars came to market, they became standard in the middle of the 1980s when ethanol vehicles accounted for 80 per cent of the automobiles sold. But, as the oil market recovered its stability and oil prices went down, sales of ethanol vehicles declined drastically. During the second half of the 1990s, sales of ethanol cars almost disappeared from the domestic market.

An historic event that revived the market in ethanol-fueled automobiles was the launching of the FFV in 2003. These cars accepted gasoline, ethanol or a blend of these two fuels in any proportion.[i] Robert Bosch was a leader in the development of the modern flex system but more innovative efforts were necessary to control both prices in the system and the cost of sensors to analyze the fuels. A major contribution was made by Magneti Marelli, an auto parts supplier of the FIAT group. Brazilian engineers at Magneti Marelli solved this issue with software technology (Teich 2006). Since their introduction into the Brazilian market in 2003, sales of FFVs have been increasing. In 2005, FFVs accounted for 49 per cent of the automobiles sold in Brazil.

FFVs completely changed the behavior of both ethanol consumers and producers. This new vehicle fuel system increased the substitutability between gasoline and ethanol for use as auto fuels. Given more flexibility in the blending of the two fuels, consumers became able to choose cheaper fuels at gas stations. The flex fuel system also increased the substitutability between sugar and ethanol for sugar and ethanol producers. Monitoring the prices of sugar and ethanol carefully, manufacturers of sugar cane derivatives can decide how to allocate their sugar cane to maximize their profits. As a result, it seems that correlations between oil prices and ethanol prices deepened at least during the period after 2003 when oil prices soared.

Figure 4: Domestic Wholesale Sales of Vehicles by Fuel Type in Brazil (1,000 Units: left axis, % of total: right axis)

Figure 5: Prices of Sugar Cane in São Paulo (US$/tonne: right axis) and of Crude Oil in the United States for January 1995 – November 2006 (US$/Barrel: left axis)

3. Geographical Distribution of the Sugar and Ethanol Sector

The policies to encourage the sugar and ethanol sector were intended to be fair and enhance industrial bases in the North-Northeast of Brazil and narrow the gaps in income between the North-Northeast region, one of the poor areas of Brazil, and the Central-South region, which contains São Paulo, the most economically and scientifically dynamic area, but the resulting distribution of indicators related to the sector are more skewed to the Central-South than those for the 1970s.[ii]

3.1. Geographical Distribution of Sugar Cane Fields and the Production of Sugar Cane

As of the year 1975, when PROALCOOL was launched, 1,969 thousand hectares of sugar cane fields were harvested. The Central-South region accounted for 60.3 per cent of this area. Since the Central-South region occupies 36.5 per cent of Brazil's national territory, the cultivation of sugar cane was already unevenly distributed at the beginning of the ethanol promotion policy. The Central-South's share remained at around 60 per cent until the beginning of the 1980s. Since the middle of the 1980s, the Central-South has regained the momentum to increase its share in the total area of sugar cane fields. In 2005, the area in Brazil almost tripled to 5,806 thousand hectares, of which 80.3 per cent was taken up by the Central-South region.

By state, reflecting the better yields of sugar cane in the State of São Paulo, there has been a higher concentration of sugar cane production in the state. São Paulo has had the largest area of sugar cane fields in Brazil: 31.5 per cent of the total in 1975. After steady increases from the end of the 1980s, São Paulo has accounted for more than half of the fields harvested since around the mid-1990s. In 2005, its share reached 53.0 per cent. The second largest area in 2005 was in the State of Alagoas (AL) in the Northeast, whose rank rose from fourth in 1975. In exact contrast to Alagoas, the State of Pernambuco, second in 1975, placed fourth in 2005.

Among the other states from the Center-South region, the State of Paraná tripled its portion from 2.3 per cent to 7.0 per cent during the same period, moving up in rank from ninth to third. The three states from the Central-West also increased in importance between 1975 and 2005; the share of Goiás increased from 0.8 per cent to 3.4 per cent; and the total of Mato Grosso (MT) and Mato Grosso do Sul (MS) (the two states formed from Mato Grosso in 1977) expanded from 0.4 per cent to 5.9 per cent (MS: 2.4 per cent; MT: 3.5 per cent).

Table 1: Area Harvested, Production and Yields of Sugar Cane

3.2. Geographical Distribution of Sugar Cane Processing Plants

Ethanol production and sugar cane processing plants are distributed geographically in a similar manner to the sugar cane fields. As of December 2006, there were 363 sugar cane processing mills producing sugar and/or ethanol registered with the Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento: MAPA). They are concentrated in the Central-South region; 281 mills are located there, while the remaining 82 are in the North-Northeast.

By state, 169 mills, or 47 per cent of the total number of mills in Brazil are located in the State of São Paulo. Following São Paulo, 30 and 29 mills are located in the States of Minas Gerais and Paraná respectively. In addition to these states in the South and the Southeast, there are major agglomerations in the States in the Central-West region; 16 mills are in the State of Goiás while Mato Grosso and Mato Grosso do Sul each have 11 mills. In the North-Northeast, the mills are concentrated in the States of Alagoas and Pernambuco, each of which has 26 plants. Paraíba is also important, with nine mills.

If we look at a satellite picture, we can see two major agglomerations of sugar cane processing plants: one around the State of São Paulo and the other near the Northeastern coast (Figure 6). But from a bird's eye view, the mills are more dispersed than the manufacturing factories. It is normal for a plant to be located inside a vast expanse of sugar cane fields. The 363 mills registered with the MAPA are sited in around 300 municipalities.

Still, using the nearest neighbor index for the mills in the State of São Paulo (Figure 6), the distribution of the mills can be seen as clustered; there is less than a 1% likelihood that this dispersed pattern could be the result of random chance.[iii]

Figure 6: The Number of Sugar Cane Processing Plants by Municipality (upper) and their Locations in the State of São Paulo (lower)

Figure 7: Production of Ethanol by State for 2005 (1,000 m^3, % of the total)

3.3. The National Trend in the Improvement of Sugar Cane Yields

PROALCOOL accelerated the improvement in sugar cane yields, too. It took a quarter of a century to increase yields by 10 tonnes per hectare from 37.5 tonnes per hectare in 1947 to 47.2 tonnes per hectare in 1972. Only seven years after the launch of the program, this productivity indicator reached 60.5 tonnes in 1982. Following the stagnant situation during the 1980s, the sugar cane and ethanol sector recovered its momentum to increase its yields in the first half of the 1990s. The yields surpassed 70 tonnes per hectares in 2002 and stayed at around 73 tonnes until 2005 (Table 1, Figure 8).

Figure 8: Yields of Sugar Cane by Region 1975-2005 (tonnes / hectare)

The Central-South region led these rapid increases in yield. As of 1975, the yield for the North-Northeast was 44.4 tonnes per hectare and that for the Central-South was 47.9 tonnes. In the first half of the 1990s, the yields for the Central-South region exceeded 70 tonnes per hectare. From 2002, the region has stayed at 75 tonnes or higher. On the other hand, there were no considerable improvements in yields for the North-Northeast before the 2000s. Even in 2005, the productivity indicator for the Northern region remained lower than 60 tonnes.

The reason for there being no significant improvement in yields in the North and Northeast can be seen by observing the situations in 1975 and 2005 at the state level. In 1975, the State of Rio Grande do Norte (RN) in the Northeast obtained 57.7 tonnes per hectare, the highest level in the country. In that year, the State of São Paulo reported 57.3 tonnes per hectare to follow Rio Grande do Norte. The situation in 2005 saw a drastic change from that in 1975. Compared with São Paulo, where 82.6 tonnes of sugar cane were harvested in a hectare of fields, only 61.0 tonnes of sugar cane were harvested in a hectare of fields in RN in 2005. Even in the State of Rondônia, which recorded the highest yield in the Northern area of Brazil, the amount was only 70.3 tons.

3.4. The Sugar and Alcohol Sector within the State of São Paulo

From the detailed description above, it is evident that the production of sugar cane and ethanol is concentrated in the Central-South region, especially in the State of São Paulo. In summary, in 2005, the State of São Paulo accounted for 53.1 per cent of the total 5.8 million hectares of cane fields, and 60.2 per cent of the total 423.0 million tonnes of national production in real terms and 56.7 per cent of the total 13,148.7 million reais of total cane production value in Brazil. From these inputs, São Paulo brewed 9,854 thousand cubic meters of ethanol, or 61.4 per cent of the total national production in 2005. The region around São Paulo is also advanced when it comes to improving sugar cane yields. This section gives more detailed observations on the geographical distribution of the industry in the State of São Paulo at the municipal level.

3.4.1. Geographical Distribution of Sugar Cane Production

Within this state, the map of the area of sugar cane harvested illustrates that sugar cane cultivation is concentrated in the area around Piracicaba, which is about 100 kilometers from the São Paulo metropolitan area, and in Jaboticabal, Jaú, Ribeirão Preto, São Joaquim da Barra and other areas that are located in belt-like zones from the center to the northern part of the state, even though the cane fields are widely distributed over the state, except in its coastal area (Figure 9, 10).

Based on the data for the proportion of area devoted to cane fields in each municipality (Figure 10), the LISA (Anselin et al. 2004) supports this observation. The LISA map in Figure 11 depicts locations with a significant local Moran's *I* statistic at the 5 per cent level and provides a classification of these locations by type of association. Figure 11 shows that there are two areas that can be classified as "high-high" (municipalities with higher values are surrounded by others with higher values); the smaller one is an agglomeration composed of fields in municipalities, including Piracicaba, and Monte Mor, that borders on Campinas. Since the high-high locations, or spatial clusters revealed by the LISA map, form the core of the clusters, it seems that the clusters of cane fields surround these two high-high areas.

As with the distribution of sugar and ethanol mills registered with MAPA at the national level, 169 plants in São Paulo are dispersed in around 130 municipalities. However, there are municipalities with multiple mills in and around the two spatial clusters of cane fields identified from the LISA. Using the nearest neighbor index, we can see that the mills also tend to be clustered.

Figure 9: Area of Sugar Cane Harvested (ha) in the State of São Paulo by Municipality and Micro-region of Campinas and Piracicaba for 2005

Figure 10: Area of Sugar Cane Harvested (per cent of the total municipality's area) in the State of São Paulo by Municipality and Micro-region of Campinas and Piracicaba for 2005

Figure 11: LISA calculation based on Figure 10

3.4.2. Sugar Cane Yields

Regarding the yields for São Paulo State, parts of the municipalities with large cane fields depicted in Figure 11 realized yields higher than the 82.6 tonnes state average, but there are also municipalities in the northwestern part of the State that realized yields superior to this average.

The high performance in cane production in the wide territory of São Paulo implies that the cane producers in each municipality have made efforts either to introduce cultivation methods and varieties that suit local conditions or to establish "state innovation systems" to transfer and share best practices. If such a system functioned well, under-productive municipalities would be able to learn from the experiences and know-how of super-efficient municipalities. This hypothesis is tested by applying the data analysis technique of so called "beta convergence" shown in Figure 13, a concept often applied to empirical studies on economic growth (Barro and Sala-I-Martin 1995). Table 2 shows the result of regression in the growth in yields between 1990 and 2004 on yields for 1990. This calculation is based on the data for 263 municipalities that have been producing cane for the entire period from 1990 to 2004. The calculated coefficient for the explanatory variable is negative and significant at 1 per cent. This result means that municipalities with lower yields at the initial year of regression grew at a faster pace to catch up with those with higher yields.

Figure 12: Sugar Cane Yields (tonnes/ha) in the State of São Paulo by Municipality

for 2005

Figure 13: Convergence in Yields (tonnes/ha) within the State of São Paulo

Table 2: Result of Ordinary Least Squares

4. R&D System for Sugar Cane and Ethanol in the Area surrounding Piracicaba and Campinas

Sugar cane yields depend on various factors, such as climate, soil, land features, irrigation, the control of weeds, diseases and pests, cane varieties, etc. In addition, varieties should be planted and grown under environmental conditions and agricultural systems that suit the selected variety. The improvements in sugar cane yields observed above are the results of a confluence of various factors, which may include the development of new varieties, the introduction of agricultural machines, biotechnology, and the sharing of best practices among farmers and millers.

The same is true for the industrial processes for producing sugar and ethanol. Millers would be able to improve the productivity of their plants through the purchase of new machines, the development of new processes, mechanisms to transfer technology and know-how from leading companies to their followers, etc. According to COSAN, one of the largest Brazilian sugar and ethanol producers in São Paulo State, the company's research and development (R&D) is not done only by its employees. This implies either the availability of R&D and technical services from local consultants and research institutes or the dependence of the private sector on universities and public institutions.

4.1. Industrial Cluster with Innovation Capability in Piracicaba and Campinas

The innovation systems for developing cane varieties today, which are to be discussed below, are based on a national network and on collaboration between experimental stations in the Northeast, the South and the Southeast. This is a common aspect of both private and public R&D institutions. This means that the national innovation system and local systems overlap or have established complementary relationships. It seems that within the framework of the national policy for promoting the sugar and ethanol sector the priority for R&D policy is the development of a national system of innovation. Even so, the major entities involved in R&D for the sugar cane processing sector are located in the municipalities of Campinas and Piracicaba and their neighboring areas, which are about 100 and 150 kilometers from the state capital respectively.

4.1.1. Piracicaba: a Center of the Sugar and Ethanol Cluster with R&D Capability

The economy of Piracicaba, which ranked 56th out of all the municipalities and accounted for 0.28 percent of the national gross domestic product (GDP) in 2004, is based on an industrial sector whose added value accounted for 47 per cent of the municipality's GDP. In this city and its surrounding municipalities, which are in the heart of the vast sugar cane zone, there are several cane processing mills, together with manufacturing companies, especially from the metallurgical and machine industries. DEDINI, a dominant Brazilian plant manufacturer with its headquarters there, is representative.

Piracicaba has also developed an outstanding capacity for providing R&D and higher education to support firms in the sugar and ethanol businesses. In Piracicaba, there are seven R&D institutions in the physical and natural sciences and 18 for higher education with more than 20 thousand university students. These figures mark the city as having the third biggest concentration of these establishments. In addition, people could go to nine institutions for vocational training in 2005. Even so, the number of employees working for these institutions is not impressive; 131 are in the R&D sector and 2,594 in the higher education sector.

The representative scientific institutions are the Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ)/USP, a top research university in Brazil in the field of agricultural science, which was founded in 1901, and the Sugar Cane Technology Center (Centro de Tecnologia Canavieira: CTC), a private R&D center dedicated to serving cane processing industries. On the ESALQ campus, there are the Center for Nuclear Energy in Agriculture (Centro de Energia Nuclear na Agricultura: CENA), which was established in 1966 to conduct scientific research, and the Center for Advanced Studies on Applied Economics (Centro de Estudos Avançados em Economia Aplicada: CEPEA), created in 1982, which is responsible for economic research on the sugar and ethanol sector as part of the Department of Economics, Administration and Sociology. More recently established on this campus is the National Biofuels Program

(Pólo Nacional de Biocombustíveis), which was launched in January 2004 by President Luiz Inácio Lula da Silva, the Minister of Agriculture and the director of ESALQ, and established in November. This program plays a key role as a kind of think tank in coordinating efforts and defining strategies for the use of different sources for biofuels and in contributing to the development of a policy to promote the production of biofuels in Brazil. As a technological incubator, ESALQTec has established four start-up companies (Leal 2006).

The Piracicaba government has already identified 69 businesses from the industrial sector that are involved in the value chains of the sugar and ethanol sector, and 10 sugar and ethanol mills (as of May 2006), including the COSAN group, universities, technical schools, R&D institutions, associations, and others. In order to consolidate the sector, the Piracicaba city administration recently promoted a policy they called the "Ethanol Cluster of the Piracicaba Area" (Arranjo Produtivo Local do Álcool: APLA). The objective of APLA is to reduce production costs and enhance the competitiveness of the ethanol cluster in the Piracicaba region, and to consolidate the cluster through coordinated action taken jointly by the Federal, State and Municipal governments, industrial groups, sugar plants, distilleries, manufacturing companies, and technological and research entities.

4.1.2. Campinas: a City with a Strong R&D Infrastructure

Campinas had the 17th largest economy in Brazil in terms of GDP and accounted for 0.83 percent of Brazil's GDP for 2004. Campinas' economic structure is urban-oriented; 57 percent of its GDP for 2002 was created by the service sector. This is reflected in the observation that this municipality is not in the core of the cane producing area identified as identified by the LISA result.

Campinas is recognized as a city with a cluster in the information technology (IT) sector, as well as a strong scientific base. The city hosts the second largest concentration of institutions for R&D in the physical and natural sciences (18 of 103 in the State of São Paulo in 2005), higher education (37 of 694), and vocational training (13 of 391).[iv] In Campinas, there are the State University of Campinas (Universidade Estadual de Campinas: UNICAMP), one of the best research universities, which was created in 1962, and other public research institutes such as the Agronomy Institute of Campinas (Instituto Agronômico de Campinas: IAC), the Telecommunications Research and Development Center (Centro de Pesquisa e Desenvolvimento em Telecomunicações: CPqD) and the Renato Archer Research Center (Centro de Pesquisas Renato Archer: CenPRA), which conducts scientific and technological research on IT and other areas. This situation seems to suit both research and the creation of new businesses, including bio-venture companies who can develop new cane varieties and provide technical services.

4.2. The R&D and Technology Transfer System for Agricultural Processes

When considering the importance of sugar cane, research resources were not necessarily allocated in sufficient amounts. Sugar cane accounted for 21 per cent of the total value of crop production in 1996, but only 4 per cent of the full-time equivalent

(FTE) crop researchers conducted sugar cane research (Beintema et al. 2001, p. 79). Nevertheless, Brazil has achieved outstanding results in the development of new varieties since the 1970s. During the PROALCOOL program, there were only 10 varieties of sugar cane available. Presently more than 500 cane varieties are being bred and the crop period has increased from 150 to 220 days (Kaltner et al. 2005, p. 24).

From these hundreds of varieties, a sugar cane and ethanol producer can choose from several to find those suitable for the fields it manages, after considering various factors such as soil, topography, the environment, company strategy, and market conditions. COSAN, for instance, uses 15 varieties. This sugar cane processor can plant varieties that are modified specifically for manual cutting and machine harvesting, or, for the end of a harvest season, those with the feature of having a shorter harvesting cycle.[v]

4.2.1. Conventional Plant Breeding

Efforts to develop new varieties, the introduction of biological pest controls and improvements in management and soil selectivity were led by the public sector. For example, the IAC, founded in 1887 as a government institute by São Paulo State did pioneering work to consolidate the sector, especially in the development of "IAC" varieties (Martines-Filho et. al. 2006). In the 1930s, this institute started research into sugar cane. Public investment in research was increased in the 1940s and 1950s. But in the 1960s, a lack of financial resources caused the decline in the amount of research on sugar cane at the IAC. Since the 1970s, partnerships between industries, the government and universities have been formed in policy environments that favor the sector to study new varieties and production processes with the objective of maintaining São Paulo's competitiveness in cane production and of breaking the technological inertia experienced during the 1960s (Fronzaglia and Martins 2006). Newly developed varieties were commercialized in the early 1980s.

Although the IAC is still a key institution in this field, there are two major initiatives that have led genetic improvements in sugar cane since the 1970s: (1) the COPERSUCAR Technology Center (Centro de Tecnologia Copersucar) and the Sugar Cane Technology Center (Centro de Tecnologia Canavieira) (both are abbreviated as CTC); and (2) the Inter-university Network for the Development of the Sugar and Alcohol Sector (Rede Interuniversitária para o Desenvolvimento do Setor Sucroalcooleiro: RIDESA). CTC has developed a series of "SP" (presently "CTC") varieties, whilst RIDESA has a group of "RB" varieties. These two varieties divide the Brazilian market in two.[vi]

Table 3: Cane Varieties registered with MAPA

(1) RIDESA

RIDESA has its roots in the National Program of Sugar Cane Improvement (Programa Nacional de Melhoramento da Cana-de-Açúcar: PLANALSUCAR) which was delineated in 1971 by the IAA. The basic objective of PLANALSUCAR was to introduce the technical and scientific infrastructure that was necessary for agricultural research: (1) by linking research and action for the creation and introduction of new varieties in diverse cane producing zones; (2) by generating a continuous process of innovation and improvement in all factors that determine the effectiveness of the technological development of cane agriculture; and (3) by achieving greater efficiency in the introduction, crossing, selection, tests for resistance against disease and pests, and the multiplication and distribution of new varieties in forms that the agro-industry can make use of. In accordance with these objectives, this program set up agricultural experimental stations in the major cane producing regions in the Northeast and the Central-South, recruited and trained technical teams, and established working methods (Szmrecsányi 1979, pp. 417-419).

In response to the abolition of the IAA and PLANALSUCAR, RIDESA was formed in 1991 by seven federal universities to follow up on PLANALSUCAR's accomplishments by continuing to provide experimental facilities and technicians, and by ensuring continuity in its research activities.[vii] Based on its organizational structure of a network of universities, RIDESA adopts a strategy for making the most of the geographical advantages of each university. The breeding and crossing of canes are the responsibility of the Federal University of Alagoas (UFAL) in the Northeast where the climate offers better conditions for flowering canes. UFAL's Serra do Ouro Flowering and Crossing Station (Estação de Floração e Cruzamento da Serra do Ouro) in the municipality of Murici, has a germ-plasm bank, which keeps more than 2,000 genotypes from those cultivated in Brazil, clones, other species related to the Saccharum genus and varieties imported from different sugar cane farming regions in the world. The seeds are sent to the experimental stations, which are mainly in the Central-South region, and these are responsible for transplanting and selection (RIDESA's website, see endnote vii).

In the case of the Program for the Genetic Improvement of Sugar Cane (Programa de Melhoramento Genético da Cana-de-Açúcar: PMGCA), carried out at the Federal

University of São Carlos (UFSCar), seeds obtained at the Serra do Ouro Flowering and Crossing Station of UFAL are planted in the experimental fields of the Center of Agricultural Sciences (Centro de Ciências Agrárias) of UFSCar in the Municipality of Araras and at the Experimental Station in Valparaíso, both in the State of São Paulo. From the third phase of selection (T3), the mills who have signed cooperation agreements with UFSCar provide experimental areas. These companies also financially sustain the program. The number of partner companies increased from 13 in 1992 to 126 in 2005 (UFSCar's website[viii]).

(2) CTC

CTC was established by the Cooperative of Sugar Cane, Sugar and Alcohol Producers of the State of São Paulo (Cooperativa de Produtores de Cana-de-açúcar, Açúcar e Álcool do Estado de São Paulo: COPERSUCAR) as the COPERSUCAR Technology Center in 1970 in the Municipality of Piracicaba. Unlike the IAC and participating universities in RIDESA, CTC is a private research institute.

COPERSUCAR, CTC's parent body, was founded in 1959 by ten mills in São Paulo and two regional entities, with the objective of marketing sugar, under the common brand name "União," and ethanol. By 1977, the number of cooperative members had grown to 77 mills, nine of which were located in Paraná, Goiás, Minas Gerais, and Rio de Janeiro. At that time, COPERSUCAR represented 86 per cent of all the São Paulo sugar producers and had 41 per cent of total sugar production and 64 per cent of total ethanol production in Brazil (Nunberg 1986, p .64).

Depending mainly on research funds from COPERSUCAR, CTC became involved in an extensive range of activities, including cultivar improvement, post-harvest research and the provision of technical services to COPERSUCAR's associate firms. Technical assistance is also provided to non-members of COPERSUCAR. The royalties and service fees received from these activities account for about one third of CTC's total budget (Beintema et al. 2001, p. 23).[ix] Besides the development of tens of cane varieties (denominated "SP") by the beginning of the 2000s, CTC achieved pilot scale production of bio-degradable plastic, the development of technologies to use cane residues for the generation of electricity, the rationalization of sugar cane transportation, and other innovations (Janssen 2002, p. 9).

Cane breeding at CTC seems to have been backed by the germ-plasm bank of COPERSUCAR. This cooperative had more than 3,000 genotypes, including a large collection of wild species, which were precursors of modern varieties of sugarcane and the source of the great genetic variety found in this plant (Macedo 2005, p. 175).

One example of the technical services provided by CTC is the CTC Benchmarking Program, which was initiated in the 1991/92 harvest season with the participation of 15 cooperating sugar mills. This program was designed with the aim of (1) making agricultural and industrial performance indices available in order to maintain continuous process improvements, (2) creating and maintaining a data bank that provides reliable information for CTC and sugar mill projects, and (3) driving CTC's R&D program. More concretely, the program compiled data gathered from COPERSUCAR's associate mills related to the performance of agricultural and industrial processes, and, by using a checklist, it constructed a comprehensive databank named "Agricultural and Industrial Mutual Control." The database allowed participating mills to evaluate whether or not they utilized the best available technology, and whether or not they adopted technologies at their maximum efficiency (Paes, et al. 2005). Apparently this program was a system or a coalition to facilitate the sharing of best practices in agricultural and industrial management.

In August 2004, the COPERSUCAR Technology Center transferred to the Sugar Cane Technology Center (Centro de Tecnologia Canavieira: CTC). Unlike COPERSUCAR's CTC, the re-organized CTC won broad support from the sugar cane processing sector. In the case of COPERSUCAR, the cooperative is formed by 87 associates, of which 29 associated mills for the 2006/2007 crop season are from the States of Minas Gerais, Paraná, and São Paulo. On the other hand, the re-organized CTC incorporates 132 associates as of February 2007, which include those from the States of Espírito Santo, Goiás, Minas Gerais, Paraná, São Paulo, Mato Grosso and Mato Grosso do Sul and many are members of the São Paulo Sugarcane Agro-industry Union (União da Agroindústria Canavieira de São Paulo: UNICA), the largest industry group in the Brazilian sugar cane, sugar and ethanol business sector.

It is said that behind the reorganization of CTC was the crisis of the sugar cane industry in the 1980s and the declining market power of COPERSUCAR. The crisis hitting the sector in the 1980s caused COPERSUCAR's total number of research staff to drop by 50 per cent, and three of its seven experimental stations were closed. (Beintema et al. 2001, p. 17). In the 2005/2006 crop season, its member mills produced 3.34 million tonnes of sugar, which is equivalent to 15 per cent of the 22 million tonnes of production in the Central-South region and 13 per cent of the national production of 25.83 million tonnes. As mentioned above, COPERSUCAR accounted for 41 per cent of the nation's sugar production in 1977 during the era of the PROALCOOL program. This decay on the part of COPERSUCAR could have been caused by PROALCOOL. Sugar producers gained access to the ethanol market, another channel for marketing sugar cane derivatives, which enabled them to reduce their level of dependence on COPERSUCAR's sales outlet for sugar.[x]

As a result, even before its restructuring, CTC shifted its strategy to putting more priority on research fields related to agriculture. Presently its research infrastructure is based on a similar system to that of RIDESA. The center, headquartered in Piracicaba, has research labs in São Paulo, and the germ-plasm bank in Camamu, the State of Bahia in the Northeast of Brazil, where new varieties of "CTC" are produced (Simões 2006). As of February 2007, this research center had developed nine CTC varieties.

4.2.2. Biotechnology

Innovations in themselves can change both the mode of scientific research and the path of technological diffusion. The application of gene modification techniques and genomics to plant breeding can lead to more efficiency and speed up the development of new varieties with more resistance to pests, higher sugar contents in the case of sugar cane and other new features that would not be obtainable from conventional plant breeding. IT can fundamentally redefine and facilitate coordination among research laboratories. Venture capital, which is a result of innovations in corporate financing and fund-raising for R&D activities, can encourage the development and diffusion of new products and services through the embedding, via the market mechanism, of cutting edge technology and knowledge.

(1) ONSA for the Xylella Project

In Brazil, ONSA (Organization for Nucleotide Sequencing and Analysis), a biotechnology research project, provided the impetus for reforming the system of innovation for sugar cane breeding. More properly, ONSA is an initiative of the State of São Paulo, created in 1997 with financial support from the state government, the national government and the industrial sector as follows: the State of São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo: FAPESP), which funded 98 per cent of the project's costs; the National Counsel of Technological and Scientific Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico: CNPq), which is linked to MCT; and the Fund for Citrus Plant Protection (Fundo de Defesa da Citricultura: Fundecitrus).

ONSA was initially a network of laboratories for the genomics of Xylella fastidiosa, a bacterium that infects orange trees and causes citrus variegated chlorosis. In other words, it is a "virtual laboratory" that consists of one bio-informatics laboratory set up in UNICAMP and 34 sequencing laboratories in the State of São Paulo networked via an intranet. The result of this research was so successful that it was published in *NATURE* (vol. 406, July 13, 2000). In addition, this collaborative network became a platform for capacity building for scientists and for sharing technical improvements (Harvey and McMeekin 2005).

(2) SUCEST: ONSA for the Sugar Cane EST Genome Project

The Sugar Cane EST (Expressed Sequence Tags) Genome Project (SUCEST) was launched in 1998 as the second research project based on the ONSA consortium, with the aim of identifying 50,000 sugarcane genes. In July 1999, clone distributions were started. In the 15 months after initiation, the project produced 291,904 expressed sequence tags (ESTs) (Telles et al. 2001). One of the project's results is the publication of a special issue of the journal, Genetics and Molecular Biology (vol. 24 no. 1-4) in 2001.

Although SUCEST followed the organizational structure of ONSA for the genomics of Xylella fastidiosa, the scope of its research activities led to an increase in the number of participating laboratories; there were 50 data mining laboratories and 24 sequencing laboratories. The lab network extended nationwide with the participation of concerned parties not only from São Paulo and other South-Southeast regions but also from the Northeast region. In addition, the degree of private sector involvement was different from ONSA; COPERSUCAR not only financed the SUCEST project but also served as a data mining laboratory.

Table 4: Structure of SUCEST

4.2.3. New Businesses invested in by Votorantim New Business

Rapid growth and the market potential of the sector and new frontiers in biotechnology attract the interest of the private sector in the sugar and ethanol businesses. The R&D activities conducted or supported by public foundations, public research institutions and universities have facilitated the creation of linkages between top researchers and the private companies with financial resources to develop new businesses.

A major example of such companies is the Votorantim Group, one of the largest industrial conglomerates whose businesses consist of financial services, cement, metals (aluminum, zinc, nickel and steel), pulp and paper, energy, agribusiness (orange juice), and chemicals. Votorantim New Business (Votorantim Novos Negócios: VNN), which is responsible for diversifying the Votorantim group's business portfolio and for managing its venture capital fund, invested in three new businesses whose founders included top researchers involved in ONSA or RIDESA. It is noteworthy that Fernando Reinach, one of the key scientists who participated in the ONSA consortium, is listed as an executive director of Votorantim New Business.

Table 5: New Biotechnology Firms with investment from Votorantim New Business

(1) Alellyx

In VNN's portfolio, Alellyx is a company in the agro-biotechnology sector. Its head office is located in the Techno Park Campinas about 100 kilometers from São Paulo. About 110 professionals work on the site, which also has a laboratory. The company also has an experimental station in Conchal-SP, 60 kilometers from Campinas.

The name is Xylella backwards, and the company was founded in March 2002 in Campinas by five molecular biologists and biotechnologists who participated in ONSA's program for sequencing Xylella fastidiosa. This new biotechnology business makes use of molecular biology methods to make targeted plants more resistant to pests, to find plants that can live in different environments and at different temperatures, and to increasing productivity in the farming of the plants. This company places a special emphasis on citrus, eucalyptus and sugar cane because 1) they aim to avoid competition with big biotechnology companies in major crops, and 2) they understand the importance of these crops in the Brazilian economy and Brazil's leading position in their cultivation and development. With its advanced biotechnologies, Alellyx serves as a foundation for Votorantim's R&D activities through partnerships with its group companies including: Citrovita, a large producer of orange juice; Votorantim Celulose e Papel S.A. (VCP), a pulp and paper manufacturer; and CanaVialis, a new business responsible for cane-related R&D and consulting businesses, which is described in detail below.

As for sugar cane varieties, the challenge for Alellyx is to increase the content of sucrose, and as a consequence, to increase the volume of ethanol obtained from the sucrose through fermentation with yeasts by making use of its scientists' expertise in molecular biology. In addition, the company is expected to develop sugar cane varieties that can have higher yields and are more resistant to dry climates and to pests than those obtained through conventional breeding. For its research, Alellyx can choose to create partnerships with universities that provide services under contracts in which intellectual property rights (IPRs) for new products belong to Alellyx, and it can also collaborate with companies pertaining to the Votorantim Group, including CanaVialis.

(2) CanaVialis

CanaVialis was established in March 2003 through a partnership between VNN and a team of researchers in the field of sugar cane breeding. This team includes two scientists, Hideto Arizono and Shizuo Matsuoka, who are well-known for their work for RIDESA in developing "RB" varieties. Headquartered in the building next to and connected with the head office of Alellyx and having some 140 researchers, this company develops new varieties of sugar cane through conventional breeding and biotechnology and provides its client mills with a package of services for agricultural management. As of December 2006, CanaVialis' customers cultivate around 600 thousand hectares. This is equivalent to about 12 per cent of the total area of cane planted in Brazil. CanaVialis is not a small firm, although it is a young business.

The conventional breeding of this firm is based on a similar network of research stations to those of CTC and RIDESA. CanaVialis has a breeding station in Maceió-AL, which stores its germ-plasm bank of genotypes from different areas of the world. New varieties bred in Maceió are selected and tested at the experimental stations in Conchal-SP, Mandaguaçú in Parana and Maceió. By testing them under the different weather and soil conditions of each station, CanaVialis can develop varieties that perform better in specific cultivating conditions. The firm produces 1.5 million seeds per year. Its seeds have been exported to countries such as Japan, Pakistan and India.

CanaVialis considers Alellyx's biotechnology to be a complementary method to that of conventional breeding. Conventional crossing can access traits almost perfectly (for example, decreases in the problems of A, B, C, and D, but not F). Biotechnology cannot create new varieties, but it can add new characteristics to canes and solve a specific problem (in this example, F). The collaboration with Alellyx allows the company to reduce the lead time required to release new varieties. As of December, 2006, the "CV" varieties of CanaVialis have not registered with MAPA. The company expects to commercialize some of them in around 2010, although normally this would take 10-15 years.

This firm believes that it is able to coexist with R&D institutions that are supported by public funds, because, for example, RIDESA depends mainly on government funds which are insufficient and are susceptible to changes in the government's fiscal position, and also involve time-consuming coordination among laboratories. The company foresees a break-even point in the next few years. Even though new varieties are at the development stage, the company seems to be able to generate revenues mainly from VNN and partly from contracts with mills to provide them with solutions and services. Its agricultural management package outlines recommendations through detailed monitoring on how best to distribute cane varieties available in the market to clients with particular agricultural conditions so as to maximize yields and profitability or reduce risks. Such information can be transferred to cane farmers who have a contract with the mills.

4.3. The R&D and Technology Transfer System for Industrial Processes

The R&D and technology transfer of industrial processes is carried out through interaction between equipment manufacturers, institutes doing technological R&D, consultants, mills and distilleries. The financial system is also crucial for the transfer of new technologies that are made concrete as new machines to farmers and sugar and ethanol producers. Trading companies can take part of the responsibility for these transfers to their clients by providing financial support. The following describes the development of this industrial process and the role of consultants by focusing on two companies.

4.3.1. Process Innovations Realized

It is said that the majority of mill operators introduced machines before or in the early 1970s, and that some of these machines are still in operation today. This means that the operators waited until 2000 to re-invest in brand-new equipment and systems. It seems that federal control of ethanol production until the 1980s permitted operators to allow their facilities to remain relatively inefficient. Nevertheless, some technological progress in agricultural and industrial processes were seen by Goldemberg et al. (2004), who measured them through changes in the prices received by ethanol producers. Based on their estimation of the learning curve, the period between 1980 and 1985 can be characterized as witnessing moderate technical progress which achieved a seven per cent fall in prices with each doubling in production, and the 1985-2002 period as an acceleration with a 29 per cent drop.[xi]

According to Oliverio (2006), a senior operational vice president of DEDINI, the equipment industry has experienced five big stages of technological innovation: 1) an increase in equipment capacity, which was addressed in the 1970s for the purpose of modernizing the sector as mentioned above; 2) an increase in overall yields; 3) a greater use of sugar cane energy; 4) a greater use of sugar cane products and by-products; and 5) a change of definition in which a sugar and alcohol mill became defined as an energy-and-food producing unit.

Technologies related to the industrial processes and equipment necessary for this technological upgrading have been developed and improved by Brazilian companies, although the industrial processes used by Brazilian mills are based on a process developed in France. In particular, DEDINI, a company founded in 1920 in Piracicaba, is dominant in this field. Oliverio's summary (2006) of Dedini's technological evolution can be seen in Table 6. With these innovations, ethanol production costs in Brazil decreased from about 90 U.S. dollars per barrel in 1980 to around 30 U.S. dollars.

Table 6: Technological Evolution of Cane Processing Plants

4.3.2. Collaboration for Process Innovation

Generally speaking, innovations in equipment are achieved through interactions between sugar and ethanol producers and the manufacturers of machines, including harvesting machines. Concretely, these millers provide manufacturers with physical locations where qualified technicians and engineers who are dispatched by the manufacturers can look for solutions and test products under development. The costs of these R&D activities are shouldered by the manufacturers. If such development projects are successful, the sugar and ethanol producers can have privileged access to new technologies and machines. The manufacturers can sell technologies and machines to recover their R&D costs.

The benefits for equipment manufacturers by collaborating with their clients are not limited to an improvement in their products and the development of new products. They can develop and test new equipment under real operating conditions by installing prototypes in mills. In addition, the construction of pilot plants enables them to collect data to improve their test plants and demonstrate their plants to potential clients. This pilot phase also facilitates the building of commercial-scale plants

The equipment manufacturing sector can find benefits in locating themselves near the users of their products given the need to interact with them to develop new equipment and solutions and to offer them a 24-hour service

4.3.3. Systems for Development at the Company Level

In order to satisfy the technological needs of ethanol producers, machinery companies form engineering teams. In the case of DEDINI, the firm employs tens of scientists and more than 300 engineers who have graduated from ESALQ and other top universities, including UFSCar, UNICAMP and USP. With experts in physics, chemistry, biology, thermal dynamics, and other fields, DEDINI can control the whole cane processing cycle, including sugar and ethanol production and the re-use of bagasse.

These employees with scientific and engineering expertise are allocated to three activities; R&D, engineering, and other, including production, marketing and project management. The engineering team is responsible for meeting requirements from its customers. To realize this, DEDINI needs to customize its products, that is to say, to utilize up-to-date technologies that are different for each order. Its engineers realize progressive innovations order by order. The R&D team is relieved of such day-to-day pressures by working on such themes as the reduction of energy consumption.

4.3.4. Public Support for the Development of an Industrial Process

A breakthrough in the re-use of the by-products generated from sugar and ethanol production is a development of the DEDINI Rapid Hydrolysis (Dedini Hidrólise Rápida: DHR). This innovative process, based on hydrolysis, to convert bagasse and straw into ethanol has the potential of almost doubling the production of ethanol without the use of additional cane; from 6,400 liters of hydrated ethanol, which is obtainable from a hectare of cane field via the present process, to 12,050 liters. At the same time it aims to reduce the hydrolysis reaction time from hours to minutes.

DEDINI embarked on the development of the DHR in the 1980s with funds from the World Bank via the Secretariat for Industrial Technology (Secretaria de Tecnologia Industrial: STI), which was under the Ministry of Industry and Commerce at that time. The STI played a key role in planning development programs, providing funds for R&D and so on during the era of PROALCOOL. The STI was the only public institution that granted funds for the development of DHR without requiring any repayment.

In the 1990s, DEDINI got a loan from the Studies and Projects Financing Agency (Financiadora de Estudos e Projetos: FINEP) under the MCT. This was not a subsidy but a loan under the favorable conditions of lower than market interest rates with a 2-3 year grace period. In 1997, a technical cooperation agreement was signed between DEDINI and COPERSUCAR to complete the development project.

In 2002, when development was moving into the phase of installing a semi-industrial unit at the site of Usina São Luiz in Pirassununga-SP, which belongs to the DEDINI group and is an associate of COPERSUCAR, DEDINI went into partnership with FAPESP to access its financial resources, which were provided through a program to support joint research for technological innovation between academic institutions/research institutes and research centers belonging to the private sector (concretely, Programa de Apoio à Pesquisa em Parceria para Inovação Tecnológica: PITE). This fund does not require DEDINI to make any repayments but to pay part of the royalty incomes it obtains from technologies developed with PITE's support.

4.3.5. The Role of Consulting Firms and Private Labs

Consulting firms and private laboratories can facilitate technology transfers by offering consulting services and analysis, by holding events and training courses, by arranging for collaboration among professionals from different entities, and so on. In Piracicaba and the surrounding area, there are such private entities, including BIOAGRI, CTC and FERMENTEC. There are also Piracicaba-based suppliers of experimental equipment and technical support, such as Marconi and TECNAL.

FERMENTEC was established in 1977 when Henrique Amorim, a director of this consulting firm, started working with three distilleries in the region of Ribeirão Preto-SP.[xii] As of 2006, this firm has more than 60 clients, including the ten biggest Brazilian mills, and companies from abroad.

The firm has 42 employees, including nine scientists with Ph.D. or post-doctoral qualifications and nine masters, and provides expertise in alcohol fermentation and laboratory control for all steps of sugar and alcohol production. Its three teams of consultants, specialized in chemistry, biology, microbiology, agricultural science, etc. visit its clients to improve their industrial efficiency. At its headquarters, the firm collects data from clients to conduct statistical analysis and evaluate all parameters that affect the ethanol production process. FERMENTEC also assesses the quality of sugar cane that affects this process.

According to the firm, a distinguished achievement is the selection of the yeast strains PE-2 and CAT-1, when there are mainly four yeast strains used in Brazil. PE-2 enabled a considerable reduction in the quantity of yeast strains necessary for fermentation. FERMENTC does not produce yeast strains to sell but provides its clients who use them with services for evaluating fermentation conditions. These yeast strains have been used not only by major Brazilian mills but also for the production of tequila in Mexico, neutral alcohol in Ecuador and ethanol in Canada.

FERMENTEC also holds training courses. Some 488 technical people from mills were trained in 2006. At its 4-day 27th annual meeting 2006, there were 18 expositors, 32 lectures and 551 participants. In addition, in 2006, there were also 25 research projects with universities in Brazil, including those located in Piracicaba (ESALQ, CENA, the Methodist University of Piracicaba [Universidade Metodista de Piracicaba: UNIMEP]), Europe and the U.S., to improve the fermentation process and sugar production.

5. Formation and Qualitative Change in the Innovation System and the Forces Driving them

By the early 20th century, the main institutions that have led cane research such as IAC, ESALQ and DEDINI had already been established. COPERSUCAR and CTC were in operation from 1959 and 1970 respectively. The basic framework for the innovation system that can be seen today was established before the introduction of PROALCOOL in 1975. PROALCOOL and subsequent policies, as well as business and technological conditions, consolidated and transformed the innovation system in Piracicaba and surrounding regions. But the innovation system in the period 1975-2000 was not the same as that post-2000. In the 2000s, the system has been in a process of transformation as a result of the macro-economic crisis of the 1980s, the market-oriented policy reform from the 1990s, and changing technological environments. The forces behind such dynamics can be explored in more detail.

5.1. Key Factors affecting the Innovation System

(1) PROALCOOL: Formation of the Sugar Processing Cluster with Innovation Capability before the mid-1980s.

A line of policies taken by IAA from the 1930s, including PROALCOOL, consisted of comprehensive instruments to help mill operating companies directly and indirectly enter the ethanol market, to renovate their facilities or to increase their scales of production. This brought significant benefits to equipment manufacturers. The infrastructure for mixing and distributing gasoline with ethanol was constructed with the participation of PETROBRAS. The national agricultural research program resulted in the development not only of new cane varieties but also of the research base organized by the inter-university network and human resources. Government policy also created the domestic market for ethanol-mixed gasoline by regulating for the blend of ethanol into gasoline and by setting the price of this blend at a rate that was comparatively cheaper than gasoline. This would be very important for ethanol producers who wanted to invest in ethanol-related facilities.

(2) Predicaments during the 1980s and the 1990s

The economic depression in the 1980s and the following slump in gas prices in the early 1990s threatened sugar and ethanol producers with bankruptcy. They tightened their R&D budgets, reined in other investments and dampened R&D activity in order to overcome the difficulty of the situation. Under the quota and price control system managed by IAA, they thought that the diffusion of new technologies would be important for the survival of the industry as a whole. The bad business conditions encouraged R&D centers, millers, consultants and equipment manufacturers to work together to survive. An innovation achieved by a mill could be made available to others. According to DEDINI, people could visit an innovative mill to copy its accomplishments, or plant makers could develop and sell similar products. But this did not necessarily mean better conditions for profit-making R&D organizations from a medium- and long-term perspective.

(3) Deregulation and the Introduction of Market Competition from the 1990s.

This situation changed in the 2000s after market liberalization and the re-organization of the plant manufacturing sector led by DEDINI through the merger and acquisition of CODISTIL and ZANINI. Deregulation developed a sense of rivalry amongst millers. They came to be less open to their competitors than before, to conceal technological information, and to keep innovations to themselves. DEDINI's dominant position in the plant market allows it to protect its IPRs. In the agricultural field, private R&D for developing new cane varieties, which was sometimes discouraged by services provided by public R&D institutions at give-away prices, was becoming economically feasible as a result of the emerging needs for agile R&D coordination. In spite of these modifications in the innovation system, collaboration among research centers, mills, consultants, and equipment manufacturers is still of significant importance.

It seems that CTC is one of the organizations affected by these structural changes of the 1980s. CTC's budget and human resources were cut not only because of the external economic environments which happened from the 1980s but also because of the withdrawal of mills from COPERSUCAR. These withdrawals were caused by the development of the ethanol market and were possibly encouraged by the deregulation of the ethanol market in the 1990s. CTC is in the process of re-consolidation after the organizational reform that was introduced in 2004 by the incorporation of UNICA's large member mills. Other positive effects of the deregulation are Alellyx and CanaVialis. These are the biggest beneficiaries of the political reforms and technological evolution in IT and biotechnology.

(4) Innovations in Complementary Technologies at the end of the 1990s.

The rapid growth in ethanol production is partly explained by the introduction of FFVs that allow drivers to choose gasoline, ethanol or a mixture of the two at any blend rate. This new technology increased the demand for ethanol in a situation of high oil prices. This feature of the FFVs could deepen the correlation between the prices of gas and ethanol. Cane processing firms became able to ship their canes as more profitable products.

Innovations in IT and biotechnology increased the number of alternatives for organizational arrangements and processes for R&D on sugar cane varieties. The increasing importance of these techniques enhanced UNICAMP's roles in breeding new canes through conventional crossing, developing human resources for R&D, and creating new businesses.

5.2. Spillovers to other Industries

The unprecedented consumption of ethanol as an automobile fuel, a well-developed infrastructure for ethanol distribution, the accumulation of Brazilian scientists and engineers with experience in R&D on sugar cane, processing plants, FFVs and other factors have all had a positive effect on the further use of ethanol and the diversification of fuel sources. An example from the transportation equipment sector is the development of an ethanol-fueled crop-dusting aircraft by Indústria Aeronáutica Neiva, a wholly-owned subsidiary of EMBRAER, one of the largest aircraft manufacturers in the world.

The Brazilian government strongly intends to apply the know-how related to cane-derived ethanol into the production of biofuels derived from other plants and vegetables, such as castor beans, oil palms, soybeans and sunflowers. As an industrial and energy strategy with an aspect of social inclusion policy, the Brazilian Government started the National Biodiesel Production and Use Plan (Programa Nacional de Produção e Uso de Biodiesel: PNPB) in December 2003 and presented the National Agro-energy Plan (Plano Nacional de Agroenergia) 2006-2011 in 2005. To facilitate their implementation, the government established a law that requires the addition of biodiesel to diesel (2% in 2008, and 5% in 2013), grants tax exemptions to biodiesel producers which acquire raw material from family farmers, and provides credit lines and other support. With respect to technological development, the federal government provides incentives and funds to activities related to the selection of raw materials that are suitable to different regional soils and climates, to the development and/or improvement of processes both for biodiesel production and for tests on equipment fueled by biodiesel, and to new uses for the co-products of biodiesel.

Mention should be made of DEDINI's leading position in the market of biodiesel plants. The company recognized bioelectricity (co-generation through the use of bagasse, straw and co-products such as stillage), bioethanol and biodiesel as the "three bios revolution." One of DEDINI's pioneering projects is the turn-key supply of biodiesel plants in Belém, the State of Pará, in March 2005 to Agropalma, a top palm oil producer in Brazil. It developed the diesel in partnership with the Chemical School of the Federal University of Rio de Janeiro. Another is the construction of the world's first 3-bios plant by Usina Barralcool in Barra do Bugres, the State of Mato Grosso, in November 2005. This factory integrates the production processes for ethanol and diesel.[xiii]

5.3. The Innovation System in the State of São Paulo centered on Piracicaba and Campinas

5.3.1. A flowchart for the sugar and ethanol cluster

Observations on industrial agglomeration in Asia often stress the role of a large firm, or "anchor firm," whose operation in an industrial site works as a driving force to encourage its suppliers and related firms to locate near it. Emphases are also placed on the role of high officials in local governments who invite investment from possible anchor firms. In recent discussions on science and technology (S&T) policy, more attention is paid to mechanisms to promote interaction between private entities within an industrial cluster and R&D institutions, including universities and public research institutes, and the role of top scientists who take a lead in scientific activities and coordinators who have enough passion, vision and experience to combine all the factors necessary to facilitate innovation in order to upgrade and make sustainable an industrial agglomeration.[xiv]

On this basis, the regional innovation system for the sugar and ethanol sector in the State of São Paulo centered on Piracicaba and Campinas is depicted in a chart based on Kuchiki's flowchart approach to industrial cluster policy (Kuchiki and Tsuji 2005, Chapter 4, Kuchiki 2007, Figure 1) (Figure 14).

Figure 14: Flowchart Approach to Agro-Industrial Cluster Policy

It should be noted that although PROALCOOL can be considered as the policy instrument for capacity building to develop the sector, ESALQ and DEDINI were created in Piracicaba before the implementation of the PROALCOOL program. This energy policy used supporting funds to build an infrastructure for the production and distribution of ethanol. Tax exemptions and low priced ethanol were also provided to encourage ethanol consumption. Universities developed the human resources required by the agricultural and industrial sectors through education or their collaboration with other universities, public research institutions or the private sector. All of these could facilitate the agglomeration of companies who were involved in the value chain of the sugar cane sector, including consulting companies and private laboratories, around Piracicaba.

Laboratories in the universities also fostered qualified scientists. They became leaders in the achievement of innovations that could be applied to the development of new cane varieties and could improve agricultural and industrial processes. Research projects funded by public bodies encouraged the development of a network of laboratories that could be inter-connected via the Internet and that could work on various biotechnology themes, some of which were closely related to the Brazilian industries that had a comparative advantage. Educated young researchers could obtain experience from participating in research projects that could become a breeding ground for specialists. The experience of collaboration during the PROALCOOL period seems to have been a foundation for the smooth progress of these research projects. In addition, Piracicaba and Campinas have a relatively better access to the São Paulo metropolitan area, and Piracicaba, in particular, is a safe place for academics and qualified specialists to live. Finally, the introduction of competition in the sector stimulated the start of new businesses by such leading scientists and researchers, which could result in the formation of an agro-industrial cluster in this area.

The development of this cluster positively fed back to the educational and research systems in the area to attract more academically-gifted students and scientists of stature. The academic community they organized and the knowledge of and experience in sugar cane, sugar and ethanol that was accumulated in the universities and research institutions could combine well with those of the private sector in the cluster to create a chain of innovation. In the case of biodiesel, the impact of such a cluster not only consolidated the cluster but also spilled over to other regions which grew other raw materials for other bio-fuels than sugar cane.

5.3.2. The Differences between the Agro-industry and other manufacturing sectors

What is different from Kuchiki's observations, which are mainly based on the manufacturing sector in Asia, is the importance of the role of local government. In Brazil, the federal government played a key role in industrial development and the São

Paulo state government also provided a substantial amount of money for research. It was only very recently that the Piracicaba municipality moved into action on APLA.

Secondly, the geographical scope of the sugar and ethanol cluster is broader than that for manufacturing. It would not be appropriate to define a city as the unique base of the cluster in the case of the sugar-cane-related sector.[xv] There are several reasons for this. For example, agriculture needs a vast area of land, and its performance is affected by initial conditions, such as climate and soil. This necessitates experimental stations near the agricultural area in addition to headquarters' laboratories in city areas or collaboration between laboratories in different cities of the country. There should also be research institutes in different cities that can build cooperation in a mutually complementary form. Information and academic results in the field of agricultural science can be made tangible and so shared among research institutes in different areas. But the emergence of new technologies like biotechnology and information technology adds momentum to reorganization by way of collaboration and a division of roles between research institutes.

Thirdly, it seems that the relation between key equipment manufacturers for sugar and ethanol production and their suppliers is not as tight as that for other machine manufacturing sectors, such as for automobiles. DEDINI said that it does not have a supplier relationship like Toyota which co-develops new models with its first-tier suppliers. DEDINI finds it more important to collaborate with millers, consultants and research institutes. Interestingly, less public support was provided to producers in the industrial process than for research related to the agricultural process in Brazil.

The fourth issue is related to the third. The existence of an anchor firm is not clear, especially a firm producing sugar and ethanol. What should be noted here is that there were several large millers that led R&D.[xvi]

5.3.3. Factors exempted from in-depth consideration of Figure 14

There are several issues exempted from the chart that was originally developed on the basis of exporting industries (Kuchiki ibid). The first is the demand side aspect. When PROALCOOL was launched, there were no large markets for ethanol as a fuel. The program paid attention to the development of a consumer market by introducing a wide range of policy instruments: the regulation to mix ethanol into gasoline; the offer of a preferential price and taxation; the development of the necessary infrastructure, including the network of ethanol-mixed gas stations; as well as other instruments. The market structure for ethanol could be one factor that accelerated the concentration of ethanol producing mills in and around the State of São Paulo. As the majority of ethanol was consumed domestically, it was rational to install mills near São Paulo, the biggest market.

The second factor is the relation between the national innovation system and its regional/local counterparts. Sugar cane breeding is based on North-South cooperation within Brazil to take advantage of the climatic conditions in the north that are favorable to flowering canes, with the scientific base and experimentation that is required for cultivating new varieties being in the south. In addition, what often occurs before any new technology or product is made available in the technological and economic sense is the development of technologies complementary to it. These imply that a local innovation system is not always independent and isolated. It is necessary to have good coordination between the national cluster and its S&T policies and their regional/local counterparts. The central government should be responsible for policies that deal with the demand side, especially when a small local government implements a cluster policy.[xvii]

6. Conclusion

PROALCOOL had a great impact on the development of the sugar and ethanol sector. It can be said that the very comprehensive policies taken by the federal government were successful in the long term although the sector experienced twists and turns. PROALCOOL, as a national policy, did not have any targeted cities in the Central-South region, but it resulted in the development of the sugar cane agro-industrial cluster around Piracicaba. Seemingly, in addition to the historical path to establish state educational and industrial systems, policies and financial support at the state level influenced the location of R&D centers and consultants within the State of São Paulo.

The flowchart in Figure 14 can partially explain the factors that affected the industrial development of the sector. But what should be kept in mind is the fact that the federal government has consistently adopted some sort of policy measures to create demand for ethanol by requiring that it be blended into gasoline. Figure 14 also provides a relatively good explanation of how Brazil created an innovative science-based agro-industrial cluster, above all the innovation system for cane varieties. Key scientists played a coordinating role by organizing research consortiums. They also take a leadership role in quickly creating new businesses based on the result of joint research.

What should be noticed are the differences in the institutional and market environments between the PROALCOOL period and the time after PROALCOOL. Before the 1990s when the federal government could intervene in the market mechanism under PROALCOOL, publicly financed research could make its results affordable for interested parties, but this may have crowded out private research. Market liberalization during the post-PROALCOOL period has encouraged companies to be innovative, which will result in promoting more innovation. On the other hand, companies are reluctant to make their experiences available to their rivals, which can prohibit technology transfers. The case of Brazilian biotechnology firms reminds one of the traditional issues regarding “which is more efficient in the creation and transfer of new technologies and the development of an industrial cluster, the market mechanism or government intervention.”

The remaining issues of this paper are related to policies taken by the municipal government, and the role of the private sector, including the anchor manufacturers of equipment, in industrial development. In particular, these should be considered in the context of interaction, (1) among companies and (2) between private companies and universities and research institutes. The former issue can be handled through the ongoing APLA in partnership with the Brazilian Micro- and Small Business Support Service (Serviço Brasileiro de Apoio às Micro e Pequenas Empresas: SEBRAE).

Behind the latter was the fact that public funds had mainly been mainly injected into research in federal universities, which made it difficult for the private sector to access such funds. In addition, for institutional reasons, it was not simple for researchers in public institutions to participate in research projects that were financed by the private sector. In response to the enactment of the so-called New Innovation Law (Lei nº 10.973, de 02.12.2004), public R&D supporting bodies are arranging programs and institutional frameworks to facilitate industry-university alliances.

In order for this law to facilitate successful collaboration between the academy and business sectors, more stress will be placed on the role of state and city governments, as well as on the local offices of the federal government, especially because of their intermediary role in matching needs and locally available resources. The role of the central government may be to design a policy framework and a coordination system to harmonize national and state policies by taking into account the present conditions of the international market, such as the CDM and the regulations on ethanol use in foreign markets, the protection of IPRs, and a wide range of other factors.

References

Anselin, Luc; Ibnu Syabri; and Youngihn Kho. “GeoDa: An Introduction to Spatial Data Analysis,” May 2004.
Available at http://www.sal.uiuc.edu/stuff/stuff-sum/stuff/stuff-sum/pdf/geodaGA.pdf (accessed on February 26, 2007).

Associação Nacional dos Fabricantes de Veículos Automotores (ANFAVEA). *Brazilian Automobile Industry Yearbook 2006*. São Paulo, 2006.

Barro, Robert J. and Sala-I-Martin, Xavier. *Economic Growth*. Singapore: McGraw-Hill, Inc., 1995.

Beintema, Nienke M.; Antonio Flavio Dias Avila; and Philip G. Pardey. *Agricultural R&D In Brazil: Policy, Investments, and Institutional Profile*, Washington, D.C.: International Food Policy Research Institute (IFPRI), Brazilian Agricultural Research Corporation (EMBRAPA), Regional Fund for Agricultural Technology (FONTAGRO), August 2001. Available at http://www.ifpri.org/themes/grp01/grp01_brazil.pdf (accessed on February 26, 2007).

Cassiolato, José E.; Helena M.M. Lastres; and Maria Lucia Maciel (eds.). *Systems of Innovation and Development: Evidence from Brazil*. Cheltenham U.K.: Edward Elgar Publishing, 2003.

Fronzaglia, Thomaz, and Renata Martins. “Coordenação de Redes de P&D: O Caso do Sistema de Inovação Sucroalcooleiro," 3º Seminário Ciência e Tecnologia na América Latina held at UNICAMP, Campinas, São Paulo, Brazil on September 14-15, 2006. Available at http://www.cori.unicamp.br/CT2006/trabalhos/COORDENAcaO%20DE%20REDES%20DE%20PD.doc (accessed on October 18, 2006).

Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP). "Science, Technology & Innovation Indicators in the State of São Paulo/ Brazil 2004," São Paulo: FAPESP, 2005.

Goldemberg, José; Suani Teixeira Coelho; Plinio Mário Nastari; and Oswaldo Lucon. "Ethanol Learning Curve - the Brazilian Experience," *Biomass and Bioenergy*, Vol. 26, No. 3, pp. 301-304, March 2004.

Greco, Alessandro. "Profile of Fernando Reinach: From Bench to Boardroom: Promoting Brazilian Biotech," Science, Vol. 300, pp. 1366-7, May 30, 2003.

Harvey, Mark; and Andy McMeekin. "Brazilian Genomics and Bioinformatics: Instituting New Innovation Pathways in a Global Context," *Economy and Society*, Vol. 34, No. 4, pp. 634-658, November 2005.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Pesquisa Industrial de Inovação Tecnológica (PINTEC) 2003*, Rio de Janeiro: IBGE, 2005.

Instituto Nacional da Propriedade Industrial (INPI). "Maiores Depositantes de Pedidos de Patentes no Brasil com Prioridade Brasileira (Entre 1999 - 2003)," Rio de Janeiro: INPI, no date, www.inpi.gov.br (accessed on July 25, 2006).

Janssen, Rainer (ed). "Workshop Proceedings," Latin America Thematic Network on Bioenergy – LAMNET 3rd Project Workshop – Brazil, held on December 2nd – 4th 2002, 2002. Available at http://www.bioenergy-lamnet.org/publications/source/bra/Workshop-BR-LAMNET-Proceedings.pdf (accessed on February 7, 2007).

Kaltner, Franz J.; Gil Floro P. Azevedo; Ivonice A. Campos; and Agenor O.F.Mundim. "Biofuels for Transportation: Brazilian Potential and Implications for Sustainable Agriculture and Energy in the 21st Century," a report prepared by Fundação Brasileira para o Desenvolvimento Sustentável (FBDS) in Rio de Janeiro, Brazil, on behalf of Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), 2005. http://www.gtz.de/de/dokumente/en-biofuels-for-transportation-in-brazil-2005.pdf (accessed on February 4, 2007).

Kuchiki, Akifumi. "Clusters and Innovation: Beijing's Hi-Technology Industry Cluster and Guangzhou's Automobile Industry Cluster," Discussion Paper No. 89. Chiba, Japan: Institute of Developing Economies, Japan External Trade Organization (IDE/JETRO), February 2007.

Kuchiki, Akifumi and Masatsugu Tsuji (eds.). *Industrial Clusters in Asia: Analyses of their Competition and Cooperation*. Hampshire, U.K. and New York: Palgrave Macmillan, 2005.

Leal, Rafael Marques Pereira. "University Contribution for Promoting Education and Innovation in Brazilian Sugarcane Productive Chain," a paper prepared for the 6th International Students Summit on Food, Agriculture and Environment in the New Century, held at Centennial Memorial Auditorium, Tokyo University of Agriculture on November 30 - December 1, 2006. Available at http://www.nodai.ac.jp/campuslife/oversea/iss/en/full%20paper%20English/2006/1-1-2%20USP%20Brazil%20fp%20.htm (accessed on February 7, 2007).

Macedo, Isaias de Carvalho (organizer). *Sugar Cane's Energy – Twelve Studies on Brazilian Sugar Cane Agribusiness and its Sustainability*. São Paulo: União da Agroindústria Canavieira de São Paulo (UNICA), 2005.

Macilwain, Colin; and Ricardo Bonalume Neto. "A Springboard to Success," Nature 407, pp. 440-441, September 28, 2000.

Martines-Filho, Joao; Heloisa L. Burnquist; and Carlos E.F. Vian. "Bioenergy and the Rise of Sugarcane-Based Ethanol in Brazil," *Choices*, 21(2), 2nd Quarter 2006, http://www.choicesmagazine.org/2006-2/tilling/2006-2-10.htm (accessed on September 6, 2006).

Mitchell, Andy. *The ESRI Guide to GIS Analysis Volume 2: Spatial Measurements & Statistics*, Redlands, California: ESRI Press, 2005.

Nunberg, Barbara. "Structural Change and State Policy: The Politics of Sugar in Brazil since 1964," *Latin American Research Review*, Vol. 21, No. 2, pp. 53-92, 1986.

Oliver, Graciela de Souza, and Tamás Szmrecsányi. "A Estação Experimental de Piracicaba e a modernização tecnológica da agroindústria canavieira (1920 a 1940)," *Revista Brasileira de História*, vol.23 no.46, pp. 37-60, 2003. Available at http://www.scielo.br/pdf/rbh/v23n46/a03v2346.pdf (accessed on February 26, 2007).

Oliverio, José Luiz. "Technological Evolution of the Brazilian Sugar and Alcohol Sector: Dedini's Contribution," *International Sugar Journal*, March 2006, No. 1287, pp. 120-129.

Paes, L. A. D.; Oliveira, D. T.; Donzelli, J. L.; and Elia Neto, A. "Copersucar Benchmarking Program," prepared for the International Society of Sugar Cane Technologists Silver Jubilee Congress, Guatemala, on January 30-February 2005, 2005.

Rezende, Fernando, and Paulo Tafner (eds.). *Brazil: The State of a Nation; Summary Edition.* Rio de Janeiro: Instituto de Pesquisa Econômica Aplicada (IPEA), 2005.

Rigolon, Francisco José Zagari, and Fabio Giambiagi. "The Brazilian Economy: General Overview." Rio de Janeiro: Banco Nacional de Desenvolvimento Econômico e Social (BNDES), June 1999.

Silveira, José Maria F. J da; and Izaías de Carvalho Borges. "An Overview of the Current State of Agricultural Biotechnology in Brazil," a paper presented at a workshop held at Bella Villagio, Bellagio Italy, 30 May – June 2005, April 2005.

Simões, Janaína. "Center of Sugarcane Technology indicates the path and sets the pace for technological innovation in the sugar and alcohol sector," *UNICAMP Innovation*, June 5, 2006. Available at http://www.inovacao.unicamp.br/english/report/news-sugaralcohol060522.shtml (accessed on February 8, 2007).

Simpson, Andrew J. G.; and Perez, J. Fernando. "ONSA, the Sao Paulo Virtual Genomics Institute," *Nature Biotechnology*, Vol. 16, pp. 795-6, September 1998.

Simpson, A. J. G.; Reinach, F. C.; Arruda, P. et al (The Xylella Fastidiosa Consortium of the Organization for Nucleotide Sequencing and Analysis). "The Genome Sequence of the Plant Pathogen Xylella Fastidiosa," *Nature*, Vol. 406, pp. 151-7, July 13, 2000.

Szmrecsányi, Tamás. *O Planejamento da Agroindústria Canavieira do Brasil (1930 1975)*. São Paulo: Hucitec, 1979.

Teich, Daniel Hessel. "A consagracão do carro flex," *Revista Exame*, n. 870, 2006.

Telles, Guilherme P.; Marília D.V. Braga; Zanoni Dias; Tzy-Li Lin; José A.A. Quitzau; Felipe R. da Silva; and João Meidanis. "Bioinformatics of the Sugarcane EST Project," *Genetics and Molecular Biology*, Vol. 24, No. 1-4, pp. 9-15, 2001.

Velho, Léa; and Paulo Velho. "Innovation in Resource-based Technology Clusters: Investigating the Lateral Migration Thesis: The Development of a Sugar-based Plastic in Brazil," Pretoria : Human Sciences Research Council, February 2006.

---

[i] FFVs are not novel. Historically, the first automobile fabricated by Henry Ford in 1896 ran on ethanol. The original "Model T" was a flex fuel vehicle.

[ii] Brazil consists of 26 States and one Federal District. Its territory is divided into five parts: North (Rondônia, Acre, Amazonas, Roraima, Pará, Amapá, Tocantins); Northeast (Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia); Southeast (Minas Gerais, Espírito Santo, Rio de Janeiro, São Paulo); South (Paraná, Santa Catarina, Rio Grande do Sul); and Central-West (Mato Grosso do Sul, Mato Grosso, Goiás, the Federal District). The North-Northeast Region is composed of the North and the Northeast and the others are grouped into the Central-South region. See Annex Map for more detail.

[iii] The nearest neighbor index (0.85 in this case) is defined as the observed mean distance (0.145229) over the expected mean distance (0.170644). For more details, refer to Mitchell (2005).

[iv] Data are obtained from the RAIS (Annual Employee Register) produced by the Ministry of Labor and Employment (Ministério do Trabalho e Emprego: MTE). Following the methodology used by FAPESP (2005, pp. 9-23), the definition of institutions for education and research is based on the National Classification of Economic Activities (Classificação Nacional de Atividades Econômicas: CNAE) at the 4-digit level of aggregation as follows: R&D in physical and natural sciences (7310-5); higher education (8031-4, 8032-2 and 8033-0); and vocational education

(8096-9, and 8097-7).

[v] In the case of Usina Alta Paulista, which is located in the Municipality of Junqueirópolis, Sao Paulo State, this usina obtained 87 tonnes of sugar cane per hectare during the 2005/06 harvest season. The principal varieties cultivated and their percentages of the total are as follows: RB72454 (16.8%); SP813250 (16.6%); RB867515 (15.7%); RB835486 (15.5%); SP801842 (9.5%); SP791011 (7.9%); RB855536 (6.5%); RB855113 (3.1%); RB855453 (2.6%); SP832847 (0.9%); and others (4.9%) (Source: http://www.usalpa.com.br/, accessed on February 5, 2007).

[vi] There are more than 500 sugar cane varieties being grown, of which the 20 most important occupy 80 per cent of the crop area. The most widely used variety is RB72454, which accounts for only 12.6 per cent (Macedo p. 177). According to RIDESA's website (www.ridesa.org.br), RB varieties occupy 57 per cent of the total area cultivated in Brazil, while SP varieties occupy 43 per cent (accessed on February 5, 2007).

[vii] The universities that have been participating from the beginning of RIDESA are: the Federal Universities of Alagoas (Universidade Federal de Alagoas: UFAL), São Carlos (UFSCar) (from São Paulo State), Viçosa (UFV) (from Minas Gerais State), Paraná (UFPR), Sergipe (UFSE); the Federal Rural University of Pernambuco (Universidade Federal Rural de Pernambuco: UFRPE), and the Federal Rural University of Rio de Janeiro (UFRRJ). With the participation of the Federal University of Goiás in the 2000s, RIDESA secured experimental stations in the Cerrado, the vast Brazilian savanna where agriculture in Brazil is growing fastest.

[viii] http://pmgca.dbv.cca.ufscar.br/ (accessed on February 12, 2007).

[ix] The annual budget of CTC was around 15 million US dollars, and was raised through contributions from COPERSUCAR associates, through revenues from services rendered and from royalties. CTC's activities included: the development of new varieties of cane; technology for agricultural production; technology for the transformation of sugar cane: the production of sugar and ethanol; the creation of new products such as biodegradable plastic; and research into technology development in association with local and foreign universities (Janssen 2002, p. 8).

[x] The early 1990s, when the oversupply of sugar caused a sharp drop in sugar prices, was the period for restructuring the sugar and research system in Brazil. PLANALSUCAR and the sugar cane breeding program carried out by COPERSUCAR were discontinued (Velho and Velho 2006, p. 8).

[xi] What should be noted is the fact that, even though the federal government determined prices until 1997, after 1985 it set them at a level below average production costs in order to defeat inflation.

[xii] Henrique Amorim took a doctorate in agronomy in 1972 from the USP and taught from 1981 to 2001 in ESALQ, according to his C.V. (http://buscatextual.cnpq.br/buscatextual/visualizacv.jsp?id=K4783649U4, accessed on February 28, 2007).

[xiii] Using sugar cane as a raw material for the chemical industry is another frontier for the industry and a challenge for scientists and engineers. A pioneering effort is the development project of bio-plastic, which started in the early 1990s when CTC was under pressure to look for applications of sugar cane from its associates who were faced with a slump in the sugar market. The laboratory's work to develop sugar-cane-based plastic was initiated in 1991 by CTC, the Institute of Technological Research (Instituto de Pesquisas Tecnológicas: IPT) of the State of São Paulo and the Institute of Biomedical Sciences of the USP (Instituto de Ciências Biomédicas: ICB/USP) with the financial support of MCT's fund, which was partially provided by the World Bank. It is said that these institutions had already carried out joint research in the framework of PROALCOOL or were acquainted with each other from workshops and conference rooms. That facilitated the organization of the joint research. When the pilot plant went into operation in 1995, Usina da Pedra participated in the project. After a successful demonstration, Usina da Pedra decided to produce the bio-plastic on a commercial scale on receiving a grant for the right of use to all equipment installed in the pilot plant without charge. PHB Industrial S.A. (PHBISA) was created in 2000 in the municipality of Serrana in the region of Ribeirão Preto, the State of São Paulo, as a joint venture between the Biagi Group (owner of Usina da Pedra) and the Balho Group (both are from the sugar and ethanol sector) with the aim of starting commercial production. In 2000, PHBISA closed an agreement with the Department of Materials Engineering of the USFCar (Departamento de Engenharia de Materiais: DEMa /UFSCar) to perform the characterization of the plastic and research on polymeric blends with this new material (Velho and Velho 2006, pp. 8-20).

[xiv] At least two persons often mentioned in some articles on the ONSA program played key roles by (1) overcoming organizational obstacles, such as the rigid bureaucracy of public universities, (2) introducing unprecedented payment systems to research teams in accordance with their results not seniority, and (3) by achieving scientific results. One is Fernando Perez, Science Director of FAPESP who committed 15 million dollars to the project, the biggest project ever funded by FAPESP. He also tried to break the mold of awarding small grants to individuals. Another is Fernando Reinach, who was a biologist from the University of São Paulo (Universidade de São Paulo: USP). Reinach would be one of the persons who initiated conversation on the idea of the project. In addition to these two, Andrew Simpson from the Ludwig Institute for Cancer Research in São Paulo coordinated work overall as the DNA coordinator of the project (Greco 2003).

[xv] In the case of process innovation, equipment manufacturers dispatch their engineers to the industrial sites of their clients. For millers, it is economic to operate near the sources of their raw materials.

[xvi] Even in the period around the 1930s, there were mills in the State of São Paulo which collaborated with an experimental station in Piracicaba (Oliver and Szmrecsányi 2003).

[xvii] The Clean Development Mechanism (CDM) is changing development conditions in the bio-fuel sector. This

provides less populated countries with a new opportunity for industrial development and may decrease the risk of any over-supply of sugar cane that might be caused by a sudden drop in oil prices.

Table 1: Area Harvested, Production and Yields of Sugar Cane

	1975	1980	1985	1990	1995	2000	2005
	Area Harvested (in 1,000 hectares)						
Brazil	1,969	2,608	3,912	4,322	4,638	4,882	5,815
North-Northeast	**782**	**1,036**	**1,337**	**1,511**	**1,328**	**1,150**	**1,152**
North	15	10	7	17	16	17	21
Northeast	766	1,026	1,330	1,494	1,312	1,133	1,131
Center-South	**1,188**	**1,572**	**2,575**	**2,811**	**3,310**	**3,730**	**4,664**
Southeast except SP	439	410	542	552	470	495	582
São Paulo (SP)	621	1,008	1,666	1,812	2,259	2,485	3,085
South	104	113	196	207	292	376	454
Center-West	23	41	171	240	290	373	543
(Percentage of the total harvested area)							
North-Northeast	39.7	39.7	34.2	35.0	28.6	23.6	19.8
Center-South except SP	28.8	21.6	23.2	23.1	22.7	25.5	27.2
São Paulo	31.5	38.7	42.6	41.9	48.7	50.9	53.0
	Production (in 1,000 tons)						
Brazil	91,525	148,651	247,199	262,674	303,699	326,121	422,957
North-Northeast	**34,686**	**48,394**	**68,050**	**72,473**	**61,384**	**59,772**	**61,960**
North	458	458	405	784	725	916	1,085
Northeast	34,228	47,935	67,645	71,689	60,659	58,856	60,875
Center-South	**56,839**	**100,257**	**179,150**	**190,201**	**242,316**	**266,349**	**360,997**
Southeast except SP	16,295	18,474	29,859	24,609	26,092	28,168	37,181
São Paulo (SP)	35,600	73,041	125,872	137,835	174,960	189,040	254,810
South	4,033	6,491	12,478	13,630	21,687	24,660	31,228
Center-West	911	2,250	10,941	14,126	19,577	24,481	37,778
(Percentage of the total production)							
North-Northeast	37.9	32.6	27.5	27.6	20.2	18.3	14.6
Center-South except SP	23.2	18.3	21.6	19.9	22.2	23.7	25.1
São Paulo	38.9	49.1	50.9	52.5	57.6	58.0	60.2
	Yields (in tons/ha)						
Brazil	46.5	57.0	63.2	60.8	65.5	66.8	72.7
North-Northeast	**44.4**	**46.7**	**50.9**	**48.0**	**46.2**	**52.0**	**53.8**
North	29.6	46.6	59.6	44.9	44.6	54.2	52.7
Northeast	44.7	46.7	50.9	48.0	46.2	51.9	53.8
Center-South	**47.9**	**63.8**	**69.6**	**67.7**	**73.2**	**71.4**	**77.4**
Southeast except SP	37.1	45.1	55.1	44.6	55.6	56.9	63.9
São Paulo (SP)	57.3	72.4	75.5	76.1	77.5	76.1	82.6
South	38.6	57.5	63.7	65.7	74.3	65.5	68.8
Center-West	38.9	54.7	64.0	58.9	67.6	65.6	69.5

Source: IPEA (1975, 1985), IBGE (1995, 2005).

Table 2: Result of Ordinary Least Squares

Dependent Variable: Growth in Yields ($Yields_{2004}/Yields_{1990}$)				
	Coefficients	Std. Error	t-statistic	
Intercept	6.044	0.260	23.266	***
ln (tons/ha) 1990	-1.148	0.060	-19.152	***
F-statistic	366.797 ***			
Adjusted R-squared	0.583			
Residual standard error	0.175			
Number of observations	263			

Note: Significant at 0.01.

Source: Author's production based on data of IBGE.

Table 3: Cane Varieties registered with MAPA

Institution	Location	No of Varieties
Cooperativa de Produtores de Cana, Açúcar e Álcool do Estado de São Paulo Ltda. (COPERSUCAR)	Piracicaba - SP	29
Centro de Tecnologia Canavieira (CTC)	Piracicaba - SP	12
Universidade Federal de São Carlos (UFSCar)	São Carlos - SP	10
Universidade Federal de Alagoas (UFAL)	Maceio - AL	7
Instituto Agronômico (IAC)	Campinas - SP	2
Universidade Federal de Viçosa (UFV)	Viçosa - MG	2
Agropav Agropecuária Ltda	Promissão - SP	1
Usina da Barra S/A Açúcar e Álcool	Barra Bonita - SP	1
		64

Note 1: COPERSUCAR carried out R&D at CTC (Centro de Tecnologia Copersucar) in Piracicaba-SP by 2003.

Note 2: UFSCar, UFAL and UFV are members of RIDESA (the Inter-university Network for Development of the Sugar-Alcohol Industry).

Note 3: SP (São Paulo), AL (Alagoas), MG (Minas Gerais).

Source: Author’s production based on data of the Ministry of Agriculture (MAPA) (Accessed on February 26, 2007).

Table 4: Structure of SUCEST

Funding		
State Government	FAPESP (The State of São Paulo Research Foundation)	
State Government	FACEPE (Science and Technology Support Foundation of	
Industry	COPERSUCAR	
Organizational Structure		
DNA Coordination	Paulo Arruda	UNICAMP
International Cooperation	William Lee Burnquist	COPERSUCAR
Bioinformatics Coordinators	João Meidanis	UNICAMP
	João Carlos Setubal	UNICAMP
Heads of Central Sequencing Labs	Fernando Reinach	USP
	Paulo Arruda	UNICAMP
ONSA Laboratories		
Data Mining labs	50 Laboratories in the States of SP, RJ, AL, BA, RN, PE, PR.	
Sequencing labs	24 Laboratories in the States of SP, AL, PE.	
National Partners		
Paulo Cavalcanti Gomes Ferreira	UFRJ	
Gianna Maria Griz Carvalheira	UFRPE (Federal Rural University of Pernambuco)	
Angélica Virgínia Valois Montarroyos	IPA (Empresa Pernambucana de Pesquisa Agropecuária, Agriculture & Livestock Research Agency)	

Note: SP (São Paulo), RJ (Rio de Janeiro), AL (Alagoas), BA (Bahia), RN (Rio Grande do Norte), PE (Pernambuco), PR (Parana).

Source: Author's production from SUCEST's website.

(http://sucest.lad.ic.unicamp.br/en/, accessed on February 11, 2007).

Table 5: New Biotechnology Firms with investment from Votorantim New Business

	Alellyx	**Scylla**	**CanaVialis**
Year of Foundation	Feb-02	May-02	Mar-03
Business Fields (main products)	Biotechnology (sugar cane, eucalyptus, citrus)	Bioinformatics	Classic Breeding Biotechnology (sugar cane)
Key Scientists	Fernando Reinach	João Meidanis	Sizuo Matsuoka Hideto Arizono
Activities engaged in by the Key Scientists	ONSA network	ONSA network SUCEST	Development of the RB varieties

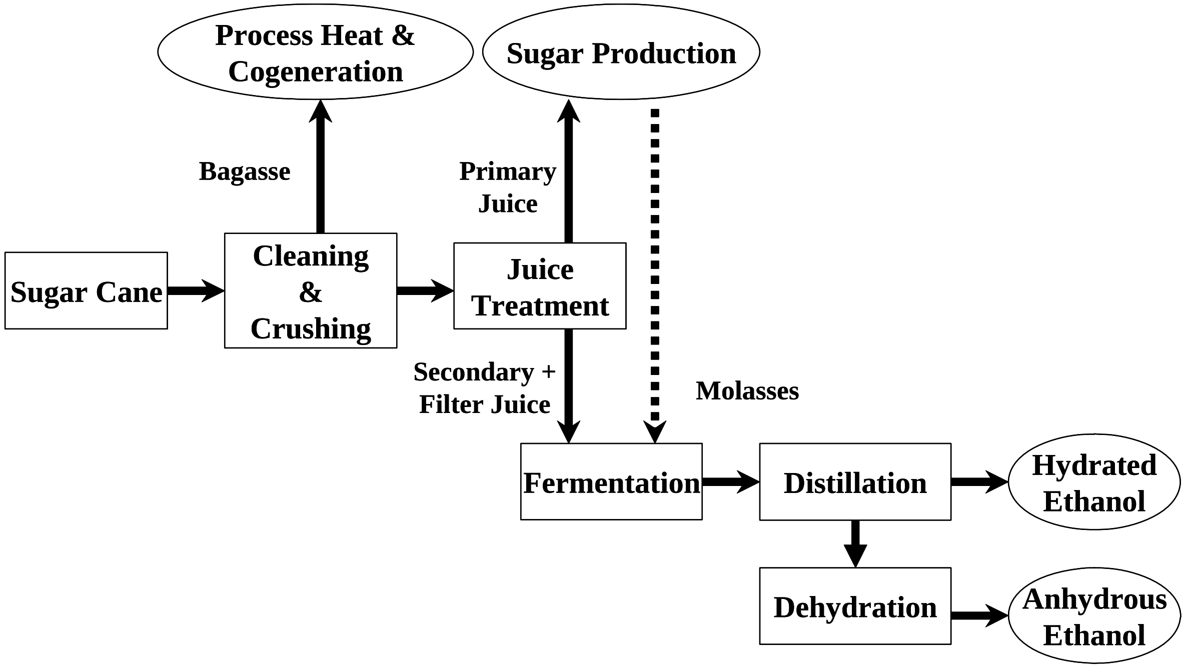
Source: Author's production from companies' websites.

Table 6: Technological Evolution of Cane Processing Plants

	Beginning of PROALCOOL	Present
Crushing capacity (tons of cane/day)	5500	13000
Fermentation time (h)	24	4-6
Total steam consumption (kg/ton of cane)	600	380
Total yield (liters of hydrated ethanol/ton of cane)	66	86

Source: Author's partial extract from Figure 3 in Oliverio (2006).

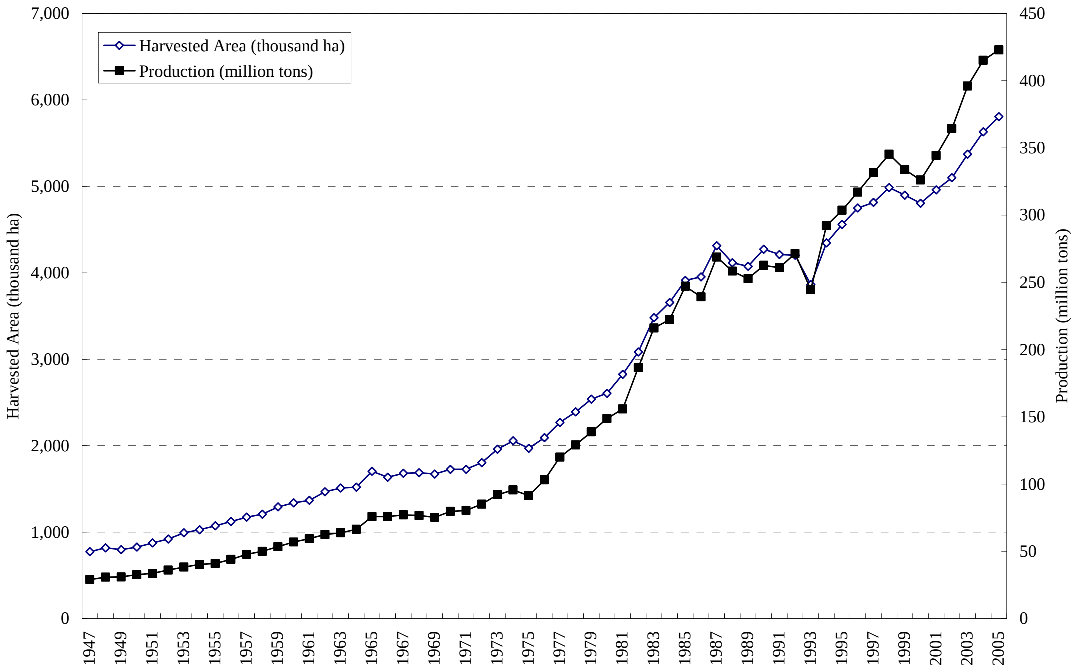
Figure 1: Sugar and Ethanol Production Chain



Note: About 75% of ethanol comes from sugar-cane juice (close to 85 liters per tonne of sugarcane). The other 25% comes from molasses, produced during sugar production (close to 335 liters per ton of molasses). (Source: MME, Brazilian Energy Balance 2004, p. 16).

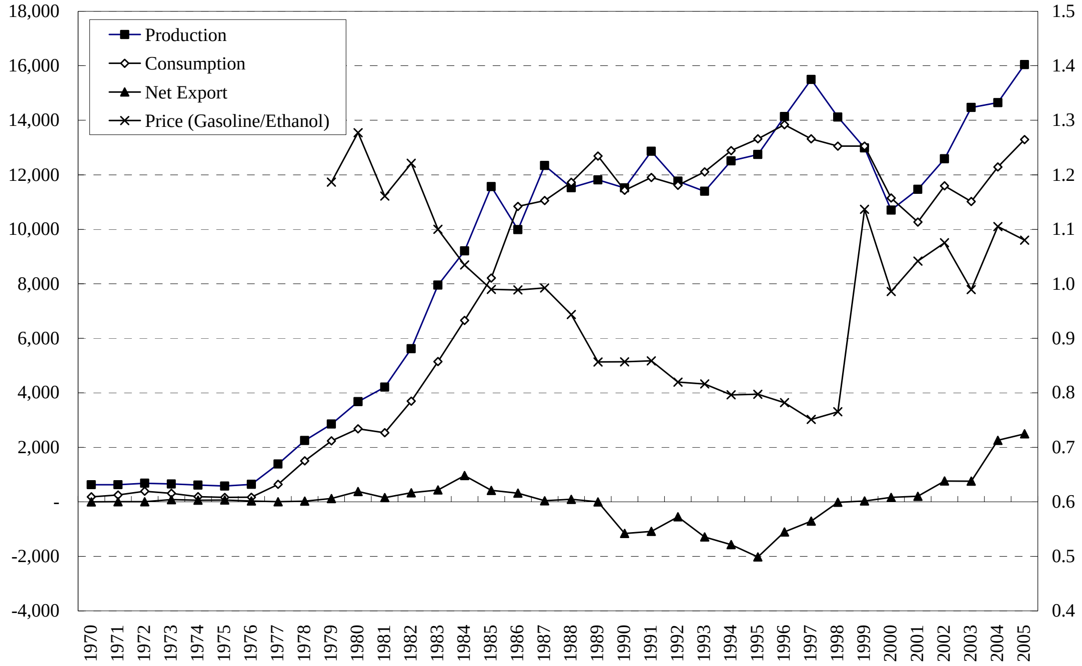
Source: Power point materials prepared by Luiz Carlos Corrêa Carvalho presented at the Brazilian Chamber of Commerce in Great Britain on November 8, 2005.

Figure 2: Area of Sugar Cane Harvested (thousand ha: left axis) and Production (million tonnes: right axis) in Brazil for 1947-2005



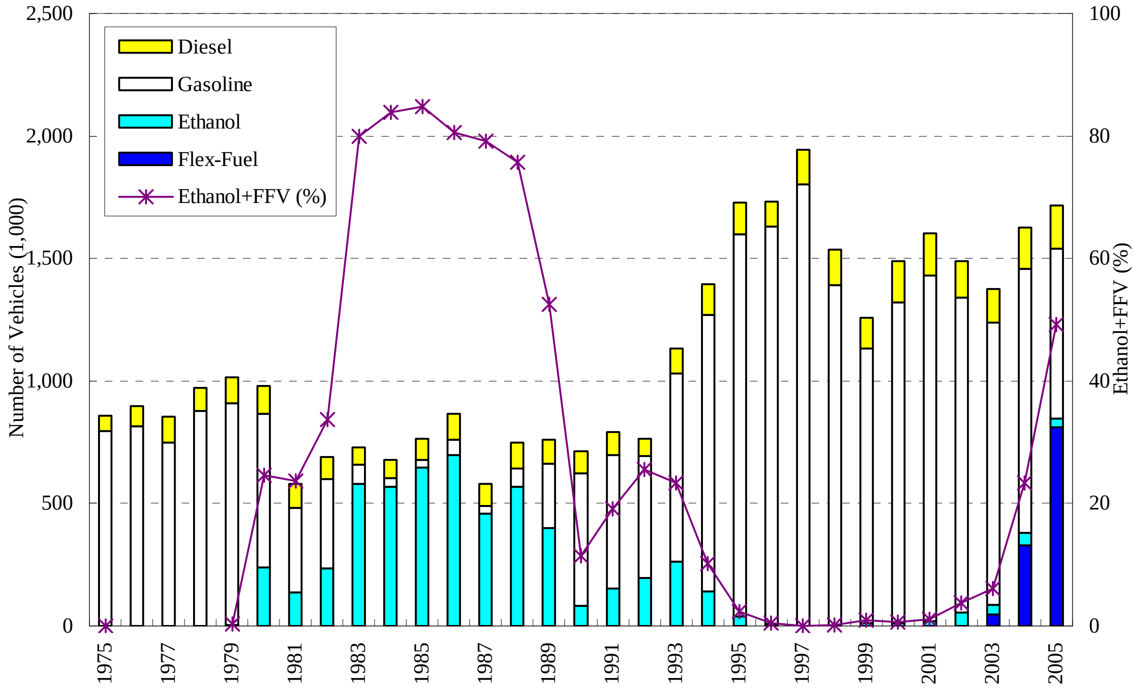
Source: Author's production based on statistics of IPEA (data for 1947-2004) and IBGE (data for 2005).

Figure 3: The Production, Consumption and Net Exports of Ethanol for 1970-2005 (1,000 m^3: left axis) and Price Ratios for 1979-2005 (Gasoline/Ethanol: right axis) in Brazil



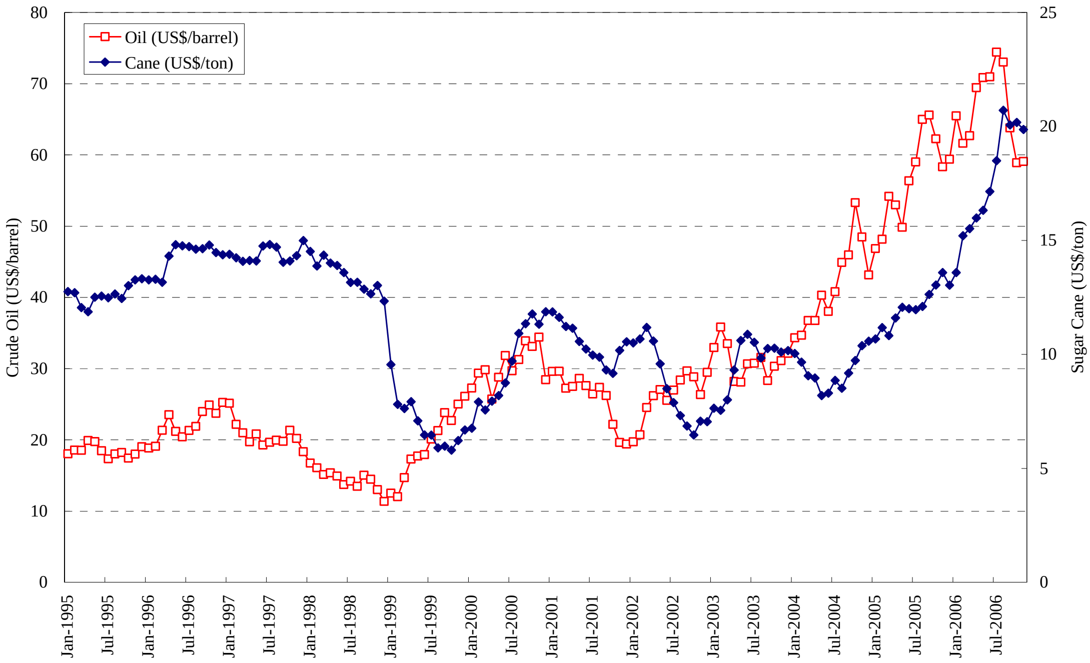
Source: Author’s production based on BEN, 2006.

Figure 4: Domestic Wholesale Sales of Vehicles by Fuel Type in Brazil (1,000 Units: left axis, % of total: right axis)



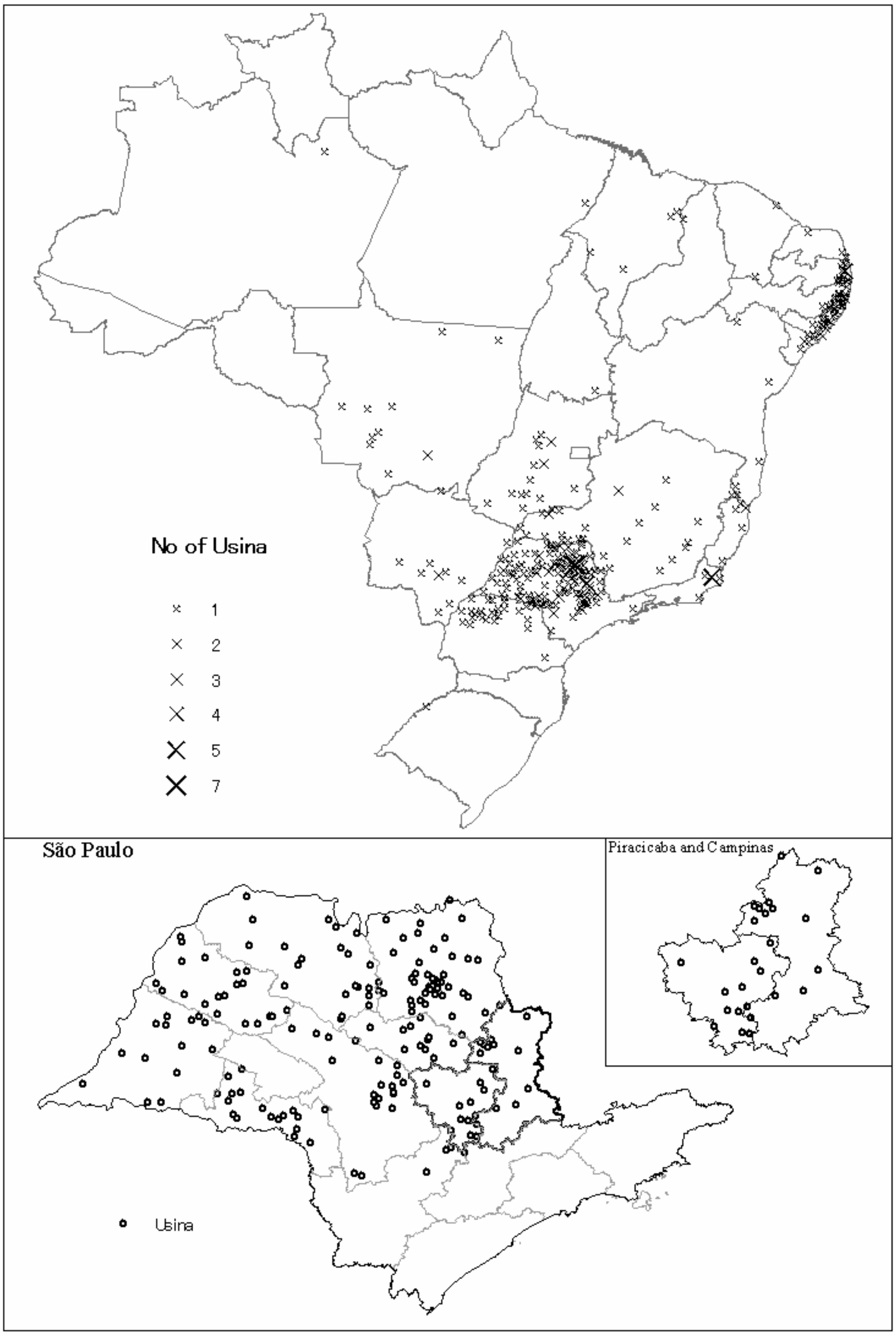
Source: Author's production based on ANFAVEA (2006), p. 62.

Figure 5: Prices of Sugar Cane in São Paulo (US$/tonne: right axis) and Crude Oil in the United States for January 1995 – November 2006 (US$/Barrel: left axis)



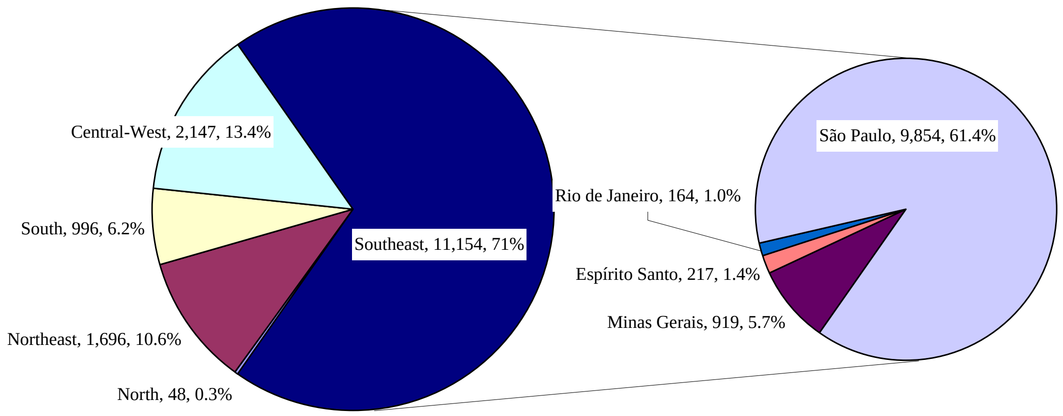
Note: Cane Price (Producer Price in São Paulo) and Crude Oil (WTI Spot Price, FOB).
Source: Author's production based on U.S. EIA and FGV (websites accessed on February 24, 2007).

Figure 6: The Number of Sugar Cane Processing Plants by Municipality (upper) and their Locations in the State of São Paulo (lower)



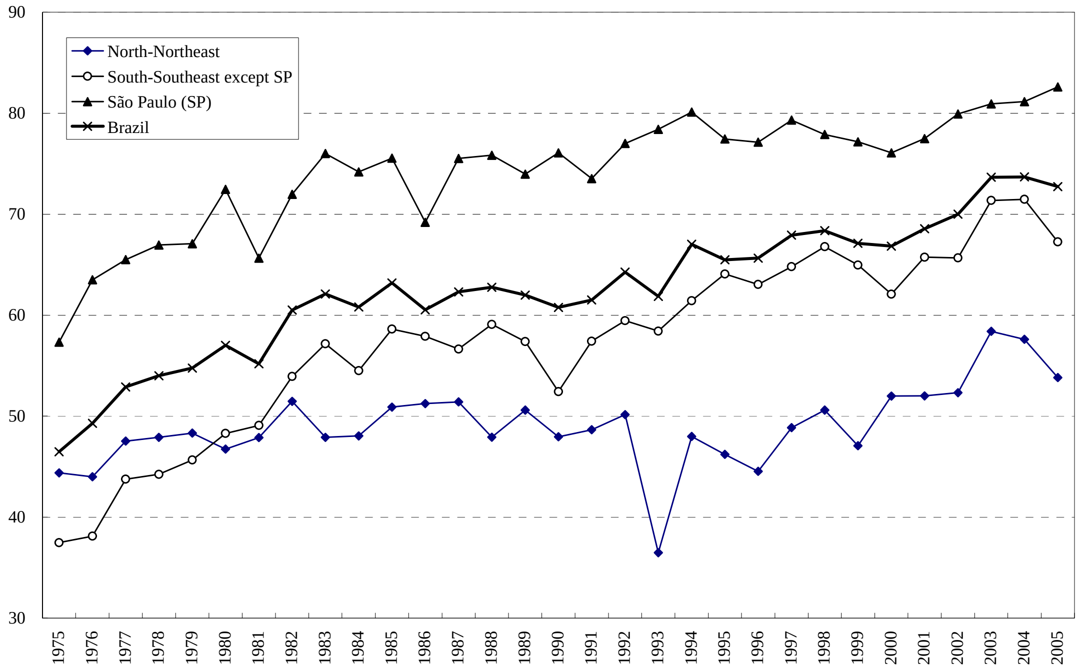
Source: Author's production based on data of MAPA. The co-ordinates of the sugar cane processing plants (usinas) were obtained from CTC on February 15, 2007.

Figure 7: Production of Ethanol by State for 2005 (1,000 m^3, % of the total)



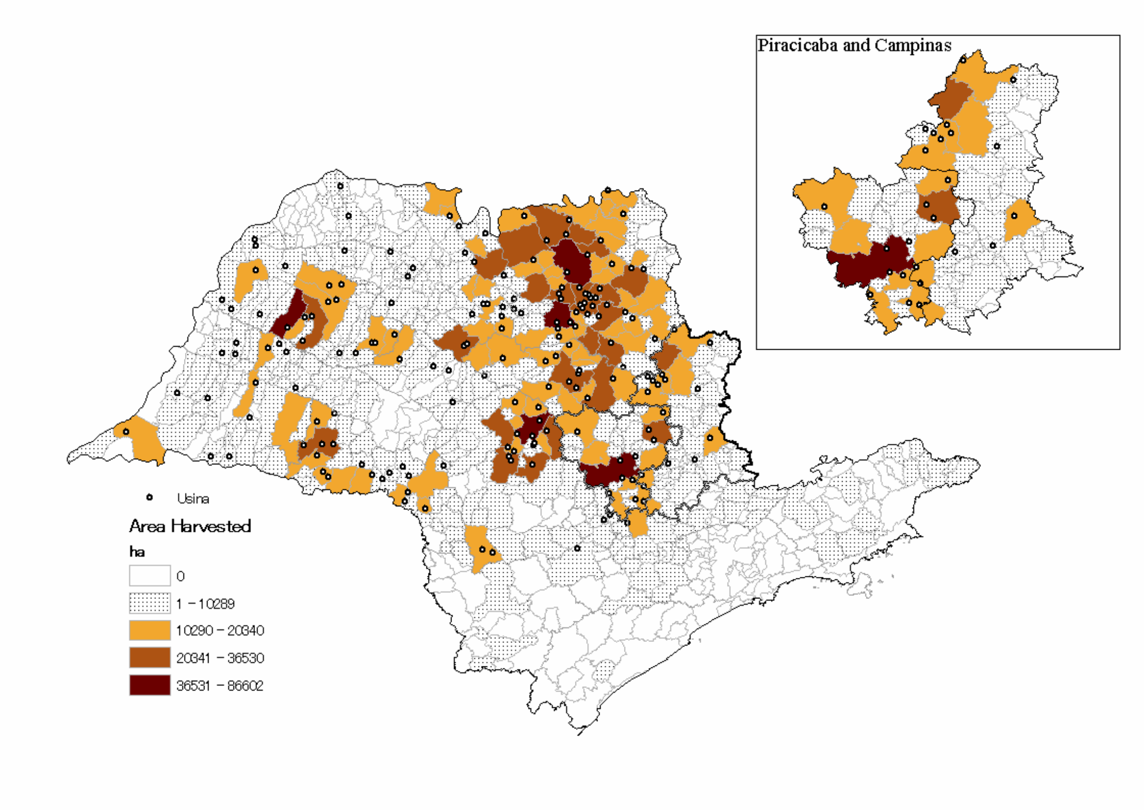
Source: Author's production based on statistics of BNE, 2006.

Figure 8: Yields of Sugar Cane by Region 1975-2005 (tonnes / hectare)



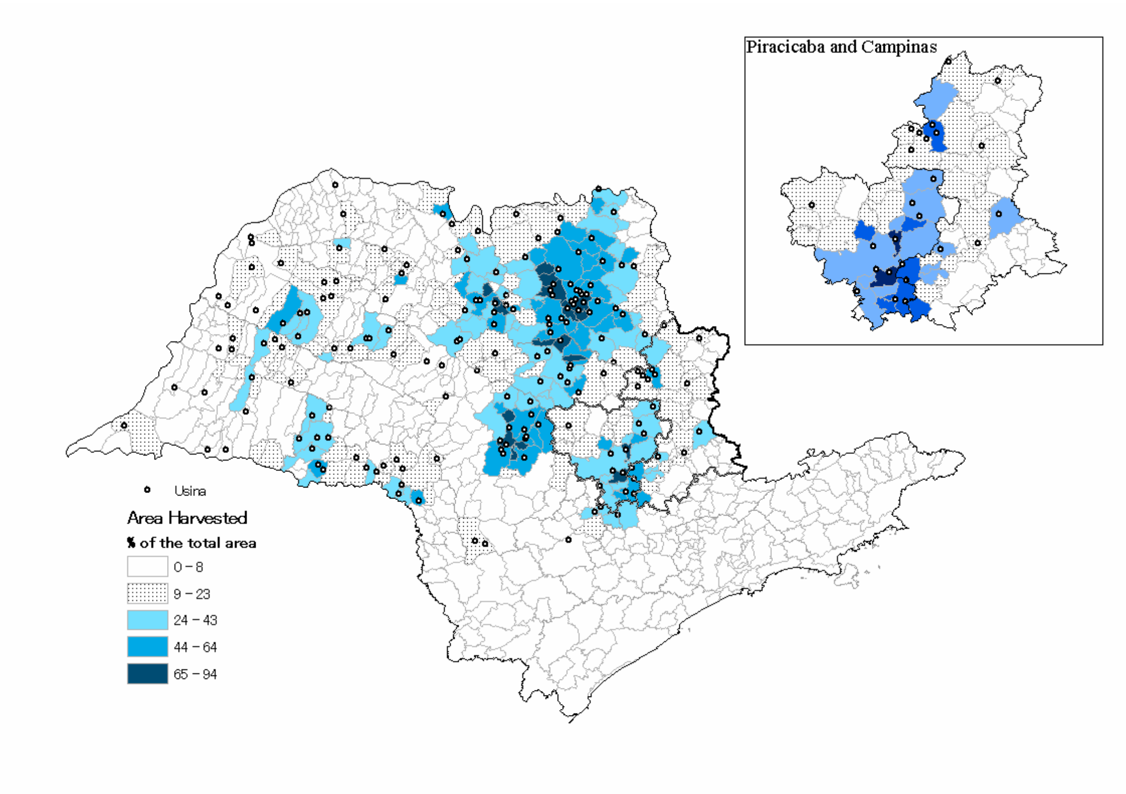
Source: Author's production based on data of IBGE.

Figure 9: Area of Sugar Cane Harvested (ha) in the State of São Paulo by Municipality and Micro-region of Campinas and Piracicaba for 2005



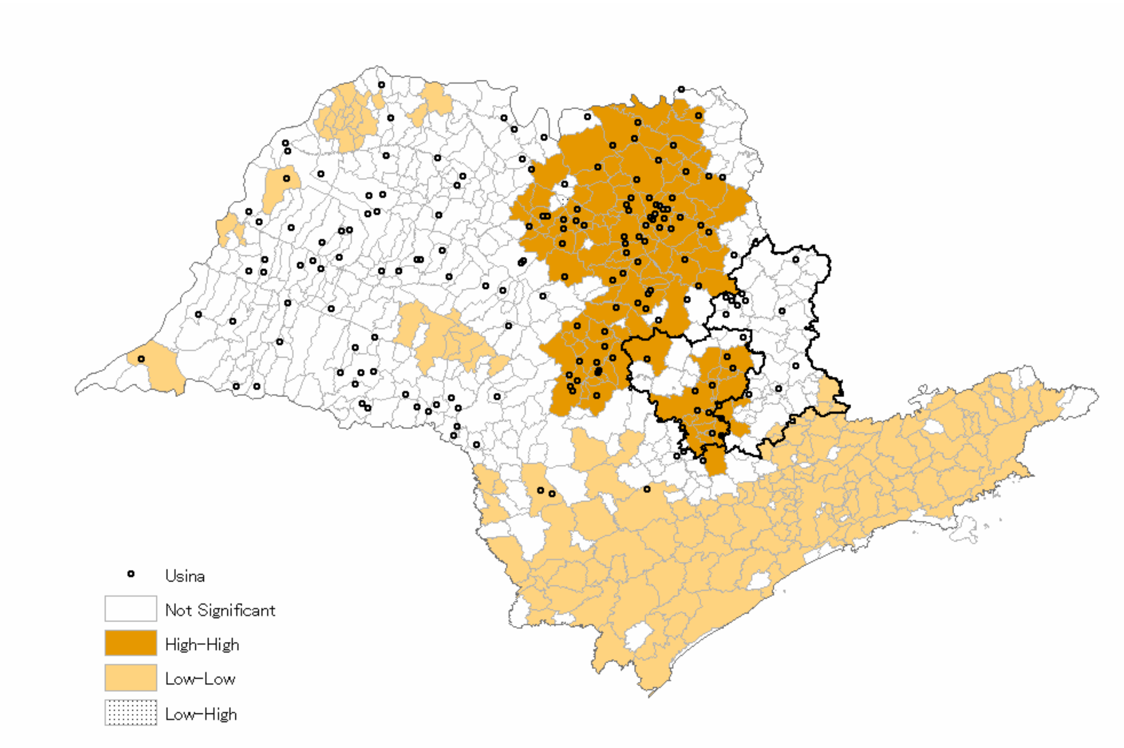
Source: Author's production based on data of IBGE. The co-ordinates of the sugar cane processing plants (usinas) were obtained from CTC on February 15, 2007.

Figure 10: Area of Sugar Cane Harvested (per cent of the total municipality's area) in the State of São Paulo by Municipality and Micro-region of Campinas and Piracicaba for 2005



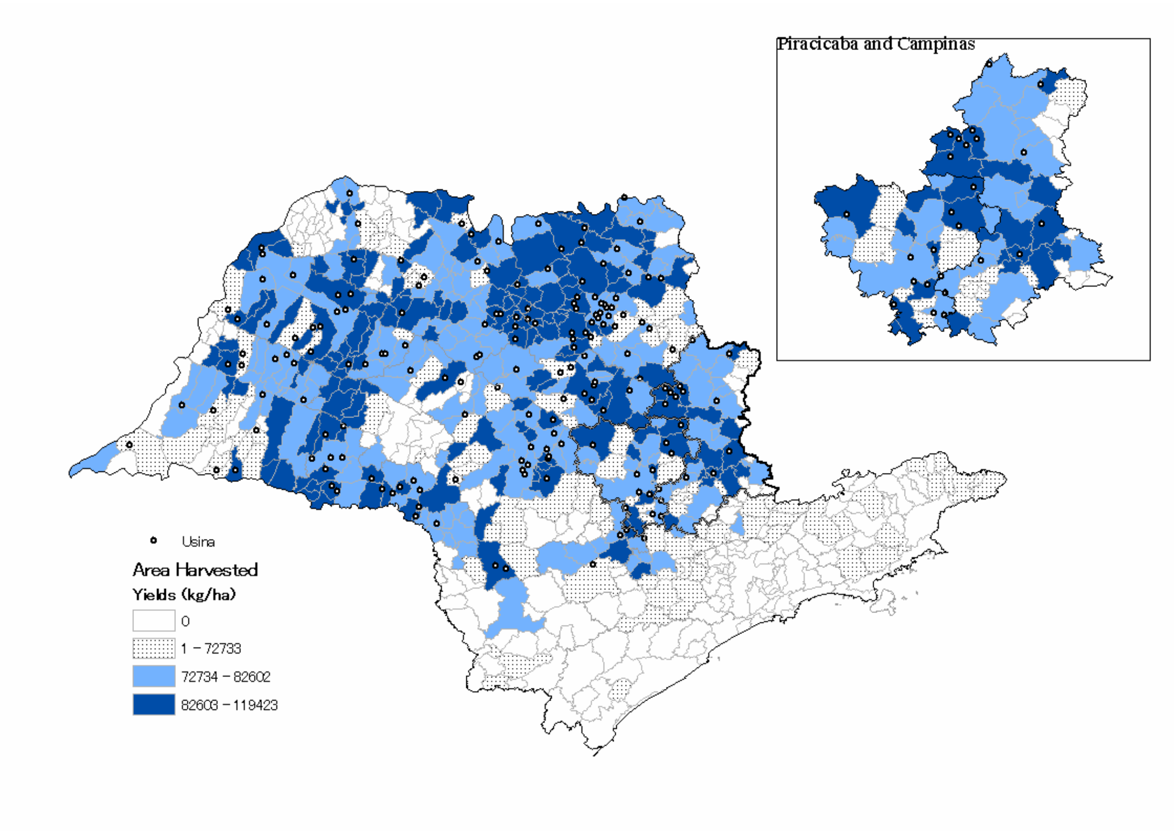
Source: The same as for Figure 9.

Figure 11: LISA calculation based on Figure 10



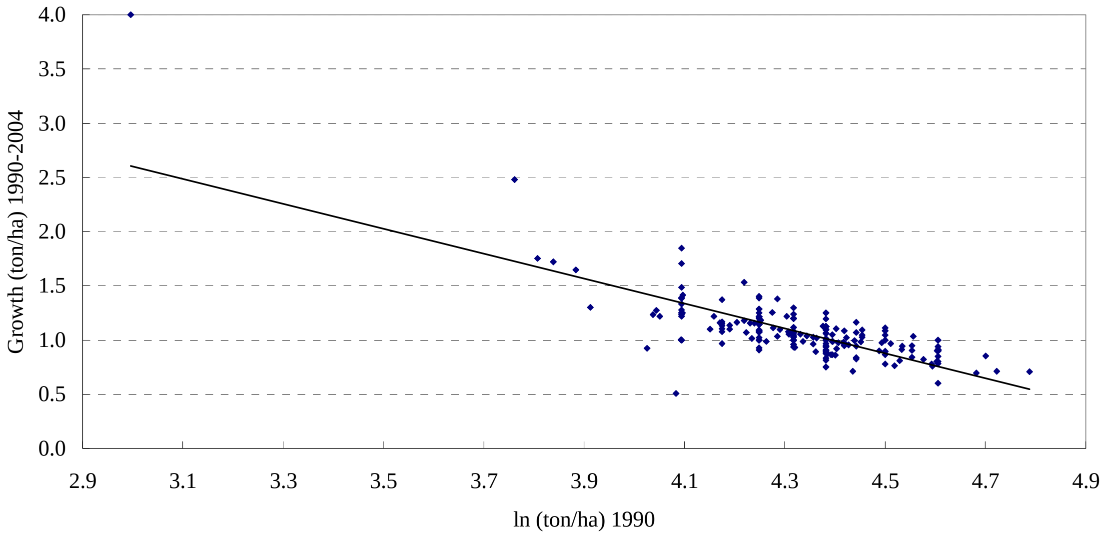
Source: Author's calculation, based on Figure 10 and depicted by GeoDa.

Figure 12: Sugar Cane Yields (tonnes/ha) in the State of São Paulo by Municipality for 2005



Source: The same as for Figure 9.

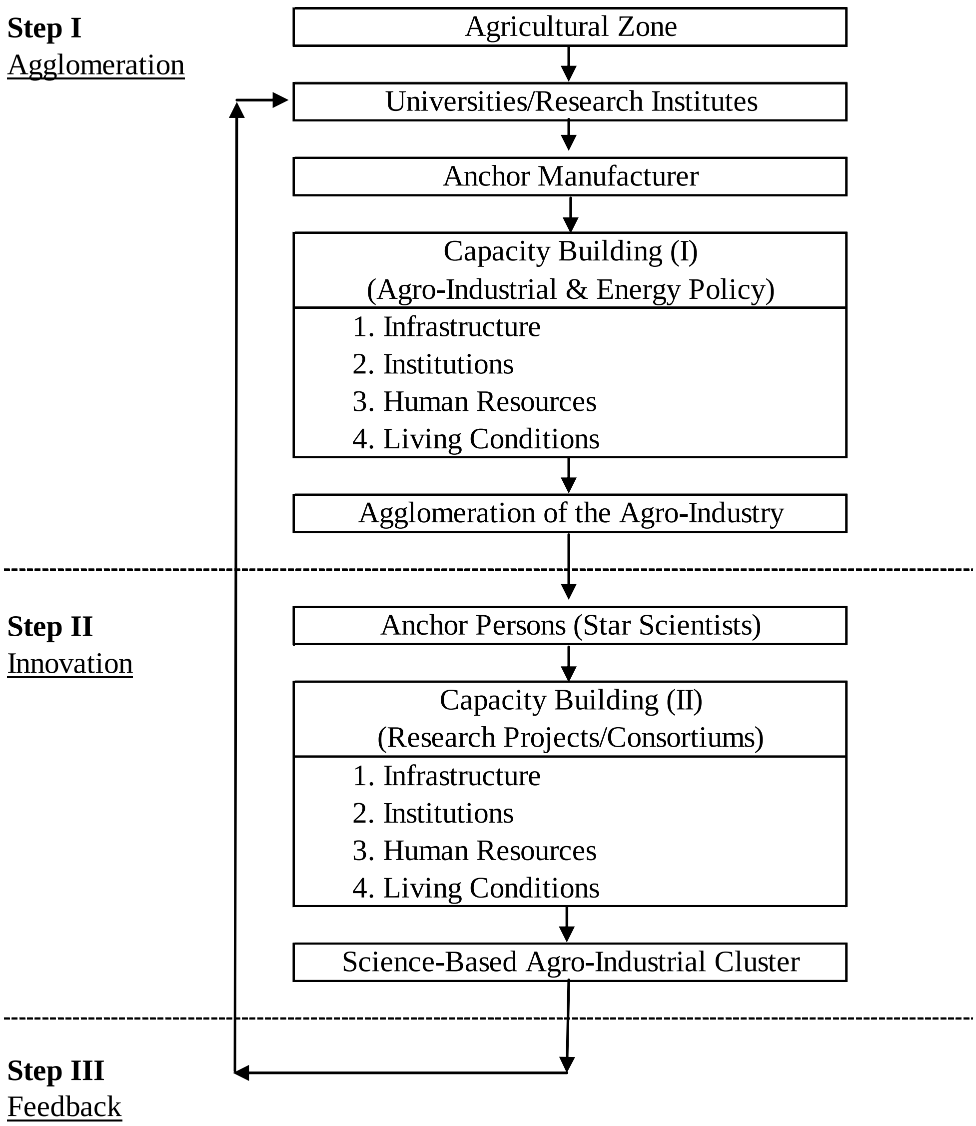
Figure 13: Convergence in Yields (tonnes/ha) within the State of São Paulo



Note: 263 municipalities for which data are available during the entire period between 1990 and 2004.

Source: Author's production based on data of IBGE.

Figure 14: Flowchart Approach to Agro-Industrial Cluster Policy



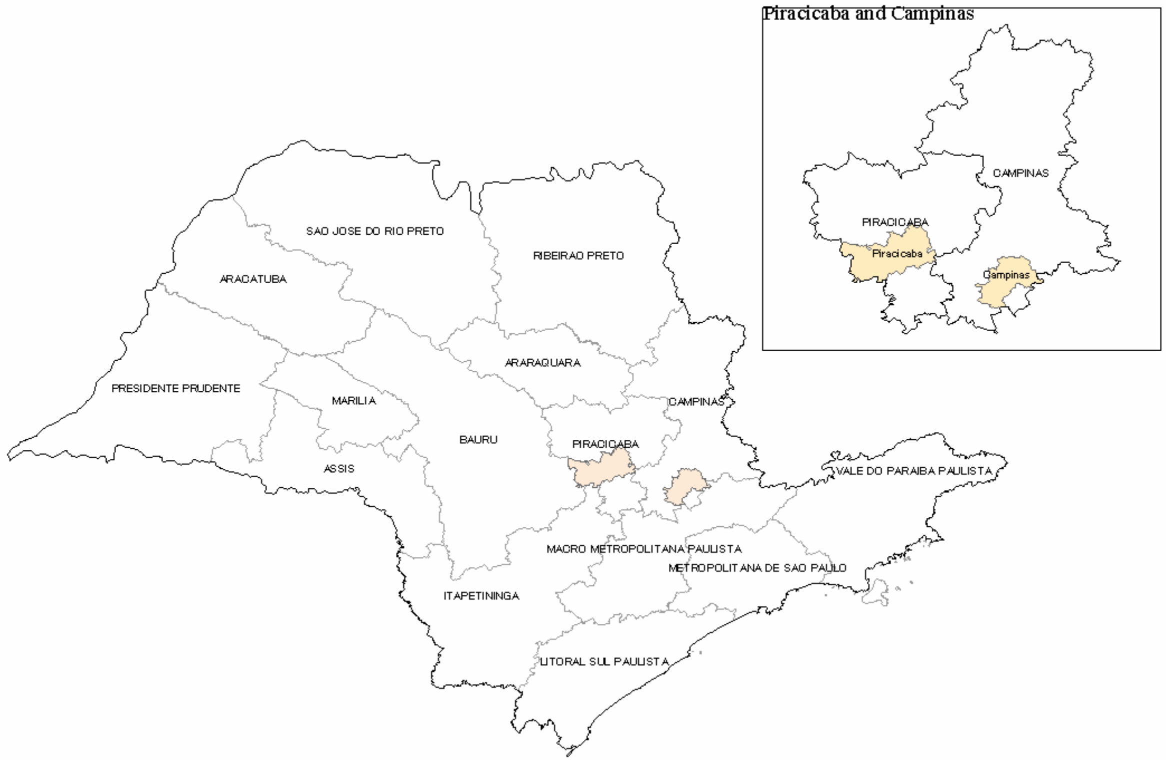
Source: Author.

Annex Map of Brazil

Region	State	Abbreviation	Region	State	Abbreviation
North	Rondônia	RO	Southeast	Minas Gerais	MG
	Acre	AC		Espírito Santo	ES
	Amazonas	AM		Rio de Janeiro	RJ
	Roraima	RR		São Paulo	SP
	Pará	PA	South	Paraná	PR
	Amapá	AP		Santa Catarina	SC
	Tocantins	TO		Rio Grande do Sul	RS
Northeast	Maranhão	MA	Midwest	Mato Grosso do Sul	MS
	Piauí	PI		Mato Grosso	MT
	Ceará	CE		Goiás	GO
	Rio Grande do Norte	RN		Distrito Federal	DF
	Paraíba	PB			
	Pernambuco	PE			
	Alagoas	AL			
	Sergipe	SE			
	Bahia	BA			

Source: Author.

Annex Map of São Paulo



Note: The colored areas in the Piracicaba and Campinas regions are the Municipalities of Piracicaba and Campinas.

Source: Author.