RENEWABLE ENERGY: A FRAMEWORK TO MODEL A BRAZILIAN CASE OF SUCCESS (PART I)

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ABSTRACT

In 1973, the first oil crisis leaded most countries to experience economic problems due to sudden unbalance in their trade balance. This leads to reactions, limited at the beginning due to short term inelasticity of petroleum demand, but relevant in long term. Brazil started the Proalcool program, which extended from 1979 to 1990, with the use of ethanol cars (E-100). In 1990 this program was ended, due to economic problems. A decline in international petroleum prices and an increase in international sugar prices, leaded to shortage of ethanol. This shortage made the users confidence to decline. From that point on, ethanol cars acquisitions almost dropped to zero. In 2003 a technological innovation, the flex-fuel electronic injection, was launched and was a huge success. In approximately three years, about 85% of all cars sold in Brazil were using this technology. It caused a boom in ethanol industry which competes in terms of resources with sugar industry. This paper presents a framework to simulate the first period of the overall program which lasts from 1970 to 2003.

1 Introduction

In late 1973, the oil price suddenly changed from an average of US$ 2.50 to about US$ 11.50 per barrel; this was the trigger to the first oil crisis. This change was a terrible surprise to many countries that dependent on petroleum imports from the Organization of the Petroleum Exporting Countries (OPEC). Due to the consequent brake on the trade balance, these countries faced severe energy and economic problems, which resulted in depression and inflation. Due to the relative low elasticity of demand in the short term, most countries could reduce only the discretionary oil demand and had to change their macroeconomic policies so as to achieve monetary, fiscal and trade balance.

The effects of this crisis in Brazil were relevant. Some short term actions were carried out, with little effect. In the long term, two successful actions were taken: the first was the investment in petroleum exploration and production, which would eventually made Brazil self sufficient in Petroleum; the other was the Proalcool program. This program was conceived with two main threads: the first was the development of ethanol, derived from sugarcane, as fuel for cars; the second was the in-country development of motor engines 100% ethanol powered.

In mid 1980's, a decrease in international petroleum prices combined with an increase in international sugarcane prices reduced attractiveness of Proalcool program. As a consequence, the percentage o ethanol usage in Brazilian cars fleet reduced from 50% in 1988 to 40% in 1994. In parallel, there was a shortage of ethanol supply which decreased the confidence of end users. In early 1990 Proalcool program was deactivated.

In 2003 a technological innovation, the flex-fuel electronic injection, was launched in Brazil became do dominant design with a huge success. Bosch developed this technology in the USA with two sensors: one in the feed line to evaluate the percentage of ethanol and gasoline in the moisture; and the other in the exhaust line to evaluate the proportion between fuel and air, so as to optimize the combustion in the engine. This technology was not suitable to be applied in Brazil due to use of hydrated ethanol. Magnetti-Marelli changes the flex-fuel electronic injection, changing its software, so as not to have to use the feed line sensor. Flex-fuel electronic injection in Brazil uses only one sensor and the calculation of the moisture proportion is performed by software.

This reduction in the number of sensors and the adaptation for Brazilian conditions made this technology attractive for Brazilian cars manufacturers. In 2003 Volkswagen do Brazil launched its first flex-fuel car. In six years almost 100% of cars sold in Brazil are flex-fuel. The end user may use either ethanol or gasoline in any proportion and this is decision takes place at the gas station, no longer when he was deciding to buy a car. In other words the decision of using either gasoline or ethanol has effect in the short term, no longer in the long-term.

The introduction of this technology coupled some industries: petroleum; sugarcane; food; land and others. Figure 1 shows the high level integration of these industries. An early study of the consequences of this coupling can be of interest to public policies which could optimize the interests of several stakeholders, such as: the Government; environmentalists; the different stakeholders in those industries; the population and others.

An additional and relevant aspect of this early analysis is that the Brazilian agricultural frontier is still far from its edge; this would allow a long-term analysis which could be used for other countries developing biomass fuels.

This paper presents the contextualization of this study. It presents a subsystem diagram and two causal-loops diagrams of these markets. This paper is organized in five sections:

section one is this brief introduction; section two tells the history of the Proalcool program an Flex-fuel technology in some more detail; section three shows the subsystem diagram for the simulation, as it is perceived now; section four shows the Dynamic Hypothesis, through a set of causal loops diagrams; section five shows some conclusions and suggestions for further studies.

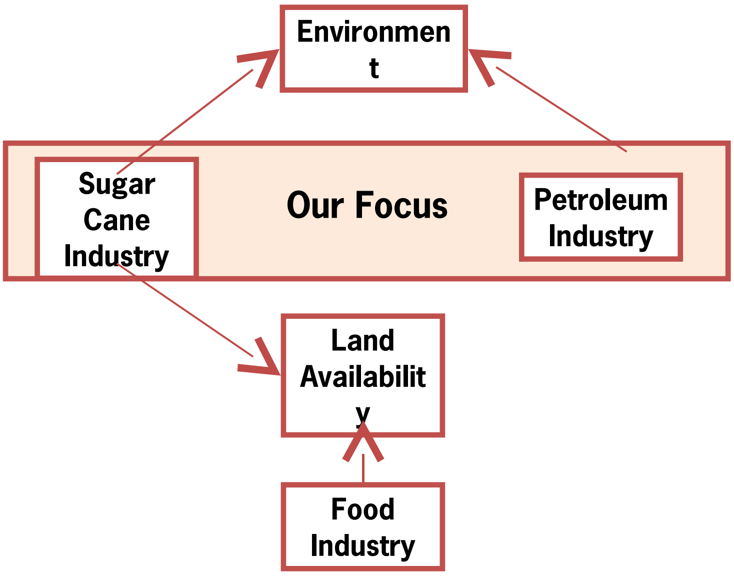

Figure 1 - Focus of this paper

2 Historical Context

From 1950 to 1973 the oil world demand had grown steadily at a pace of 9.5% per year. Petroleum costs were very stable and used to vary from two to three US dollars per barrel. In 1973, the Organization of the Petroleum Exporting Countries (OPEC), established a new production level and costs policy which raised the barrel price to 11.65 US dollars. This change in prices cause an economic and energetic crisis in those countries which were highly dependent of petroleum imports from OPEC countries. This period is known as the first oil crisis.

Combined with the relative short-term inelasticity in oil demand, this increase in prices caused a serious unbalance in trade balance of most developed countries. This unbalance caused stagnations and inflation. The Organization for Economic Co-operation and Development (OECD) countries reacted by decreasing discretionary oil consumption, reducing its relative importance in their energy matrix, and changing macroeconomic policies (fiscal and monetary) trying to oppose both, the economic and energetic crisis. Some of these actions have long delays and were not effective at that time.

In Brazil, the systematic use of ethanol[1], from the sugarcane, as an alternative fuel started in 1934. From 1934 to 1975 the anhydrous ethanol was added to petrol with the purpose to elevate its octane. In 1975, Brazil started its Alcohol Program, so called Proalcool. Its first goal was a modest replacement of petrol with anhydrous ethanol. In 1980 the goal became more ambitious. With this new policy a relevant percentage of petrol was replaced by ethanol. In 1971 only 1% of gasoline was replaced by anhydrous ethanol; in 1985 this percentage achieved 41%, an increase of 40% in 14 years. (LEITE, 2007)

[1] The term used in Brazil is alcohol instead of ethanol. Both terms are used indistinctly in this paper.

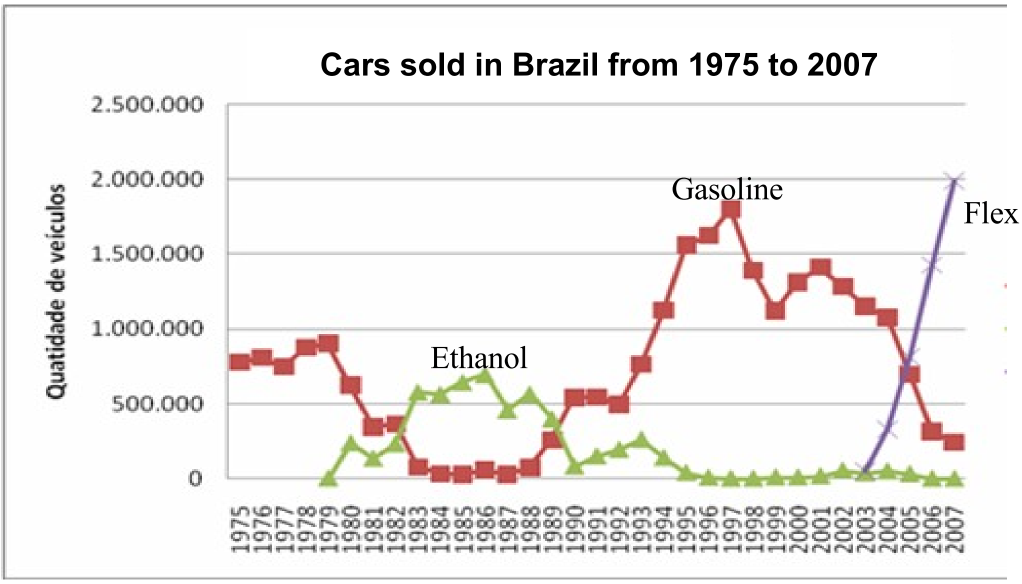

Figure 2 - Car sales in Brazil - from 1975 to 2007

Proalcool program had several projects. One was the in-country development of E-100[2] cars. In 1978, an agreement between the Brazilian Government and the National Association of Motor Vehicle Manufactures[3] (Anfavea) established the beginning of E-100 development. In 1979, only one year later, the first E-100 was in the market. Considering the design and manufacture issues as well the logistics of fuel, this can be considered a remarkable achievement.

In 1988-1989, Proalcool was de-activated due to economic pressures: high inflation and low product growth for more than fifteen years. The total ethanol consumption dropped from 50% of total amount of fuel consumed in 1988 to 40% in 1994. During the 1980's 70% of vehicles sold in Brazil where E-100. The ethanol fleet was relevant and it would take a decade to be deactivated (LEITE, 2007).

In the early 1990's with the end of Proalcool, the rise in international sugar price and the decrease in the international oil prices there was a shortage of ethanol. This shortage generated a lack of confidence in consumers, which would charge its price later. Consumers no longer bought ethanol powered cars and the E-100 sales dropped down almost to zero, from 1990 to 2003. The remainder ethanol cars still sold were results of the sugarcane sector pressure for government incentives and the so called "*green fleet*", part of the Government cars fleets should be E-100.

A technological innovation, the flex-fuel electronic injection, was already available in the US. Bosch started to study this solution in 1988, in California, USA. Due to the technology adopted, Bosch solution was expensive for Brazilian patterns costs and Brazilian motor vehicle manufactures refused to use it. Moreover, dual sensor[4] technology was not suitable for Brazil due to the presence of hydrated ethanol.

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[2] E-100 cars are full (100%) ethanol powered.

[3] Associação Nacional dos Fabricantes de Veículos Automotores.

In 2003, Martin Marietta launched its new flex-fuel electronic injection technology which uses only one sensor to control the oxygen proportion in the exhausted gases; the function of sensor lambda was replaced by *software intelligence*. Bosch and Delphi launched their own versions of this flex-fuel electronic injection some months later.

The flex-fuel electronic injection was a success, see Figure 2. In 2006, two millions of cars sold in Brazil used flex-fuel injection technology. Why?

Using marketing terms, the acquisition of a new car in Brazil can be considered an acquisition of high involvement. A gasoline and ethanol (E-100) cars have no significant differences in 1980. So brand loyalty, as well as fuel loyalty, was relevant in decision process. With the ethanol shortage in early 1990's and the consequent lack of consumer confidence, ethanol cars were no longer a good option.

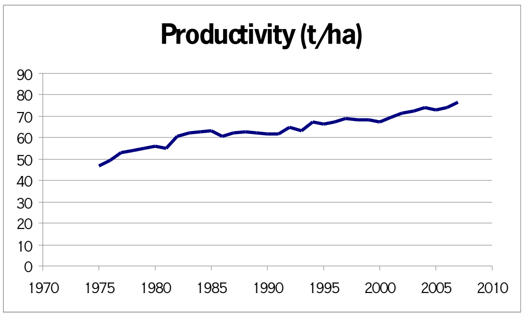
Since the flex-fuel technology lowered the level of involvement, the consumer behavior change, and the consumer behavior theory states that in these situations experiments could be done. Flex-fuel technology allows the customer to postpone its decision concerning the use of ethanol or petrol until the gas station.

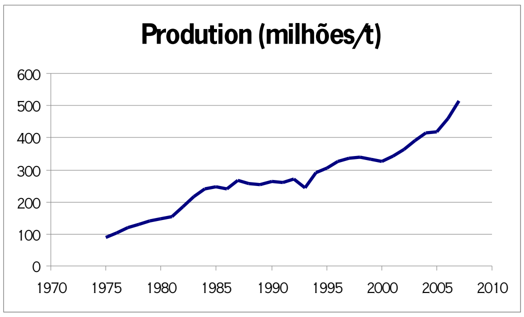
The ethanol and gasoline demand in Brazil is now much more volatile and the long-term decision of buying a gasoline car or an ethanol car is no longer necessary. One can decide what to use in minutes. Another particular characteristic of flex-fuel technology is that it strongly coupled oil and sugarcane industry, as well as other industries, such as food, land, plastic and others.

Two controversial issues remain from the Proalcool program: the first concerns its economic success; the other is what will happen in the future. The discussions concerning the first issue are not clear and have no conclusion. Since it is not a *mono-criterion* evaluation, it would be interesting to analyze its impacts in terms of energy source independence, environmental issues and employment.

Goldemberg et al. (2004) addressed some issues on this discussion. He discussed the learning curve of Proalcool program, comparing the subsidies given to sugarcane industry with other countries subsidies and how the sugarcane industry increased its productivity in 25 years.

Figure 3 shows the behavior over time of some sugarcane industry parameters. On the left, it can be seen that Productivity has increased from 46.8 ton/ha (1975) to 76.6 ton/ha (2007); it represents an increase in productivity of 63.6%. On the right hand side, it can be seen that Production has increased from 88.2 (1975) to 514.1 (2007); this represents an increase in production of 483%, almost five times in 30 years.





[4] Dual sensor flex fuel electronic injection technology uses two sensors: one is known as lambda, its function is to detect the ethanol/petrol ratio and is used to set up the injection; the other sensor is used to detect proportion of oxygen in burst gases, so as to feedback the software to adjust the moisture air/fuel.

Figure 3 - Sugarcane Production and Productivity

The second point, what is to happen in the future? It can be analyzed using some scenarios. Some relevant issues can be studied; some examples are:

a) Others energy sources are being studied all over the world, hydrogen is accepted in car industry to be the successor of petrol. If it happens, what will it be its effect on Brazilian sugarcane industry?

b) Developed countries have shown some resistance to use ethanol to replace petrol, will this resistance remain or will it be overlapped? What are the consequences of each scenario?

c) Conflicts between land usages have arisen worldwide and would be of interest; will the use of land (in Brazil) for sugarcane affect in a relevant way the production of food? When will the agricultural frontier achieve its edge?

3 SUBSYSTEM DIAGRAM

Figure 4 shows the Subsystem Diagram with five major subsystems identified so far in this project. The subsystems are: Government (GOV); Sugarcane Industry (SCI); Oil Industry (OI); Car Owners (CO); and Cars Fleet (CF). Three exogenous variables have been identified: International Sugar Price, International Petroleum Price and Cars Demand.

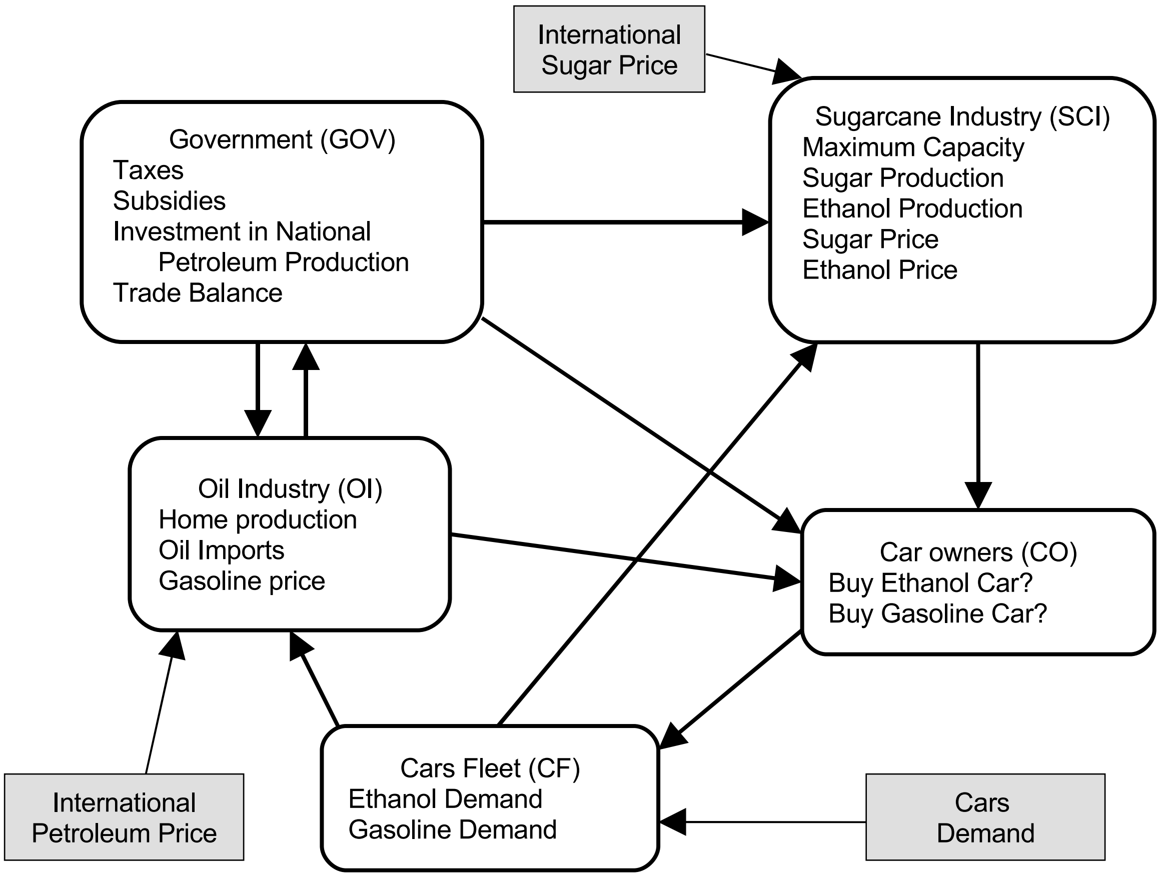


Figure 4 - Subsystem Diagram

Table 1 shows how subsystems affect each other. First column shows the origin; second column shows the word “affects”; third column shows the variable affected; fourth column shows the word “with”; and fifth column shows how the first variable affects the second. Letters representing subsystem as in subsystem diagram.

Table 1 - Who affects who and how?

WHO	AFFECTS	WHO	WITH	HOW
GOV	affects	SCI	with	Subsidies
GOV	affects	CO	with	Taxes and Subsidies
GOV	affects	OI	with	Taxes and Investment
OI	affects	GOV	with	Petroleum Importation Costs
OI	affects	CO	with	Gasoline Price
SCI	affects	CO	with	Ethanol Price
SCI	affects	CO	with	Ethanol Production
CF	affects	SCI	with	Ethanol Demand
CF	affects	OI	with	Gasoline Demand
CO	affects	CF	with	Buying either Ethanol or Gasoline Cars

Subsystem diagram shows the interactions between subsystems identified at this stage. Next item will present some causal loop diagrams that show the original Dynamic Hypothesis.

4 Dynamic Hypothesis

The renewable fuel problem we are addressing can be separated out in periods. Osiris and Fischetti (2008) suggest divide in three: the first would last from 1975 to 1989 – introduction and high sales in production and demand achieving its peak in 1985/1986; the second period would last from 1990 to 2002 – with the decrease of interest; and the third, from 2003 to today with the introduction of flex-fuel. The dynamic hypothesis developed so far encompasses only the first and second periods. The third period and its potentials consequences will be developed in other studies.

Figure 6 shows the causal loop diagram which is perceived to describe the dynamics of these periods. Fundamentally, the basic structure follows the SI model, see Sterman (2000, Chapter 9). Marketing and Word of Mouth loops were omitted for simplicity.

Gasoline Adopters, which were 100% until 1979, and Car Demand increase lead to an increase in Petroleum Imports. Figure 5 shows how Cars Demand and Gasoline Adopters increase Petroleum Imports.

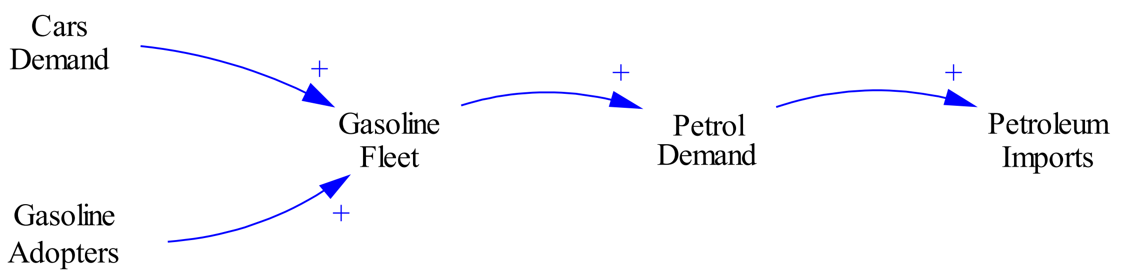


Figure 5 - Increase in Petroleum Imports

Increases in Petroleum Imports and in International Petroleum Prices, which took place in late 1973, increased Petroleum Import Costs. To react to this increase, the Brazilian Government took two actions: the first was to stimulate the use of Ethanol (E100) cars (Loops B1 and B2); and invest in national petroleum production (Loop B3).

Loop B1 shows the restrictions to buy gasoline cars. To stimulate the adoption of Ethanol (E-100) cars, the government reduced ethanol cars taxes and increased gasoline cars taxes. This policy increased the price of gasoline cars and reduced the price of ethanol cars. This policy led to an increase in Gasoline over Ethanol Car Price Ratio, which increased ethanol attractiveness, which increased Ethanol Adoption Rate, which decreased the Gasoline Adopters.

Loop B2 shows the restrictions to use gasoline as fuel. Gasoline was over taxed so as to subsidized ethanol production costs; this led to an increase in Gasoline over Ethanol Fuel Price Ratio, increasing Ethanol Attractiveness, which increased Ethanol Adoption Rate, which decreased Gasoline Adopters.

Loop B3 shows the investment in national petroleum production, which captures a long delay response. Since Petroleum Imports Costs had risen, Government Incentives to National Petroleum Production raised; this led to an increase of National Petroleum Production, after a delay of about a decade, which led to a reduction in Petroleum Imports.

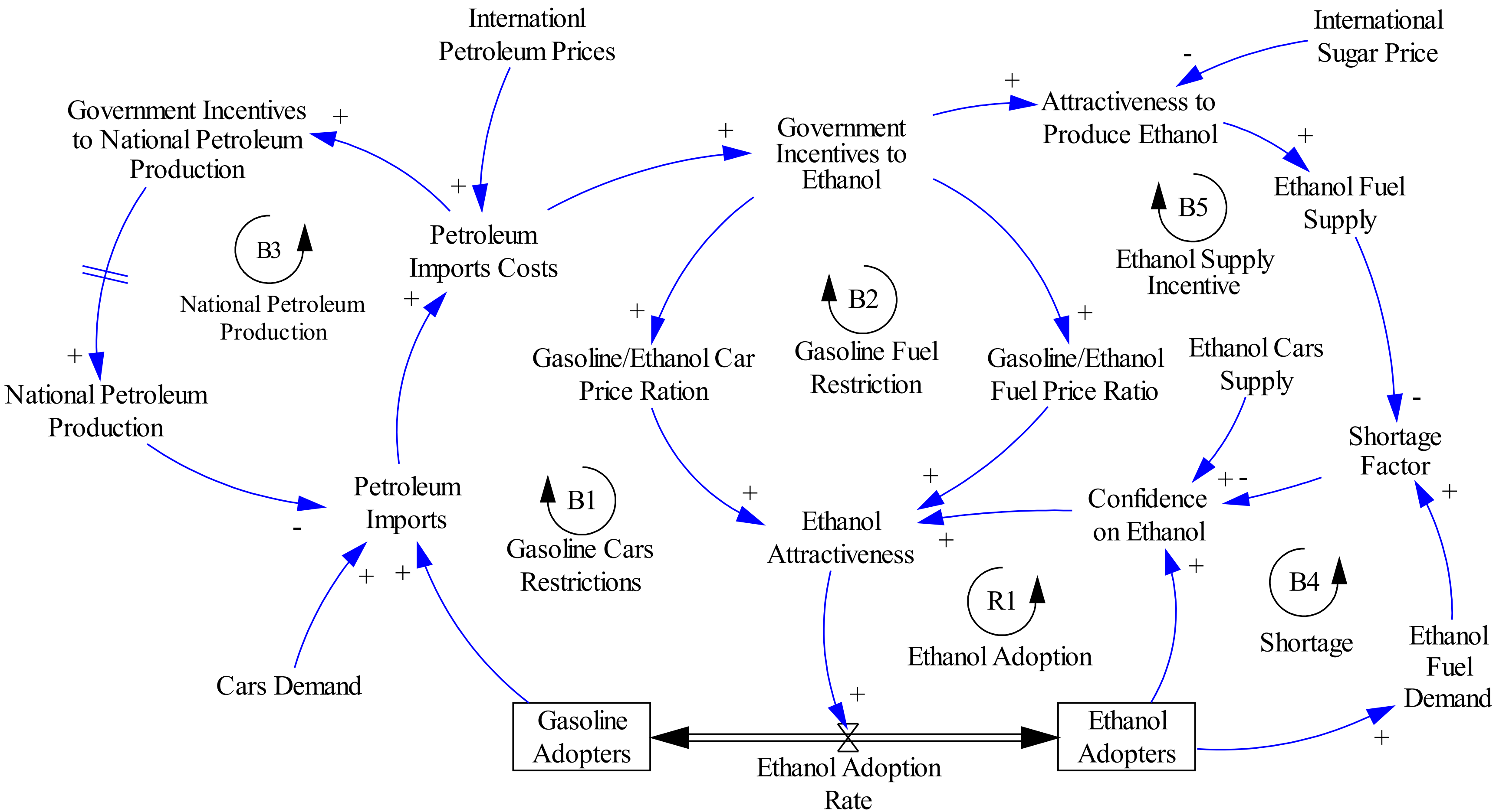


Figure 6 – Causal Loop Diagram (From 1975 to 2003)

The reduction of Petroleum Imports reduced the Petroleum Import Costs, the greatest Government problem. Since the Petroleum Imports Costs reduction decreases the Government interest in Proalcool, this will lead to a reduction of interest in the program.

The reinforcing loop R1 shows the Ethanol Adoption process. Assuming that initial marketing actions have been carried out (omitted in the diagram) there will be an initial increase in Ethanol Adoption Rate. This will lead to an increase in Ethanol Adopters and will lead to an increase in Confidence on Ethanol, which in turn will increase Ethanol Attractiveness, increasing Ethanol Adoption Rate further more.

Shortage of ethanol fuel dynamics is captured in Loop B4. When Ethanol Adopters increase, Ethanol Fuel Demand increases. Figure 7 shows how increase in Cars Demand and Ethanol Adopters will lead an increase in Ethanol Fuel Demand. An increase in Ethanol Fuel Demand will lead to an increase in Shortage Factor (Ethanol Fuel Demand over Ethanol Fuel Supply); an increase in Shortage Factor will decrease Confidence on Ethanol. This decrease in Confidence on Ethanol will lead to a decrease in Ethanol Attractiveness.

Loop B5 captures dynamics of Ethanol Supply Incentive. Government Incentives to Ethanol increases the Attractiveness to Produce Ethanol. This will lead to an increase in Ethanol Fuel Supply, which will decrease the Shortage Factor, compensating the increase in Ethanol Fuel Demand. It is relevant to observe that Attractiveness to Produce Ethanol decreases when International Sugar Price increases.

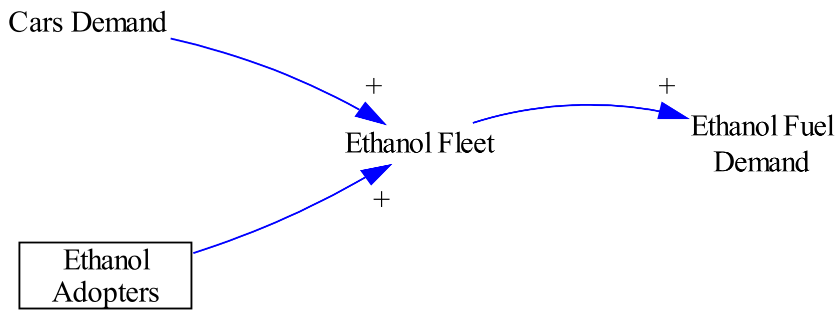


Figure 7 - Growth of Ethanol Demand due to Ethanol Adopters

Figure 8 shows the perceived dynamics of Sugarcane Industry. Since both commodities, ethanol and sugar, use the same raw material, sugarcane, there is a competition for common a resource. Senge (1994) explains what could happen in such a situation:

> The “Tragedy of the Commons” always opens with people benefiting individually by sharing a common resource – a brand-new freeway, for example. But at some point, the amount of activity grows too large for the “commons” to support. In many cases, the commons seems immeasurably large and bountiful at first, but it is either nonrenewable or takes a great deal of time and effort to replenish. The commons might be natural resources, open space, human effort, financial capital, production capacity, or market size – anything which groups of individuals depend upon in common.

Loop B11 introduces the International Sugar Demand. An increase in International Sugar Demand will increase the International Sugar Price; an increase in International Sugar Price decreases International Sugar Demand. This will lead to a balancing loop B11, International Sugar Demand.

The Sugar Production loop B12 shows how production reacts to demand. As International Sugar Price rises, Sugar Revenue will rise. Sugar Profits will rise when Sugar Revenues rises and decrease when Sugar Production Costs rises. An increase in Sugar Profits will lead to an increase in Desired Sugar Production; an increase in Desired Sugar Production will increase Sugar Actual Production; and an increase in Sugar Actual Production will decrease the International Sugar Price. Since Brazil has a great sugar (from cane) production, it is likely to be able to interfere in international sugar prices. Loop B12, Sugar Production, shows the balancing side of supply. These loops (B11 and B12) show the supply and demand behavior for the sugar market.

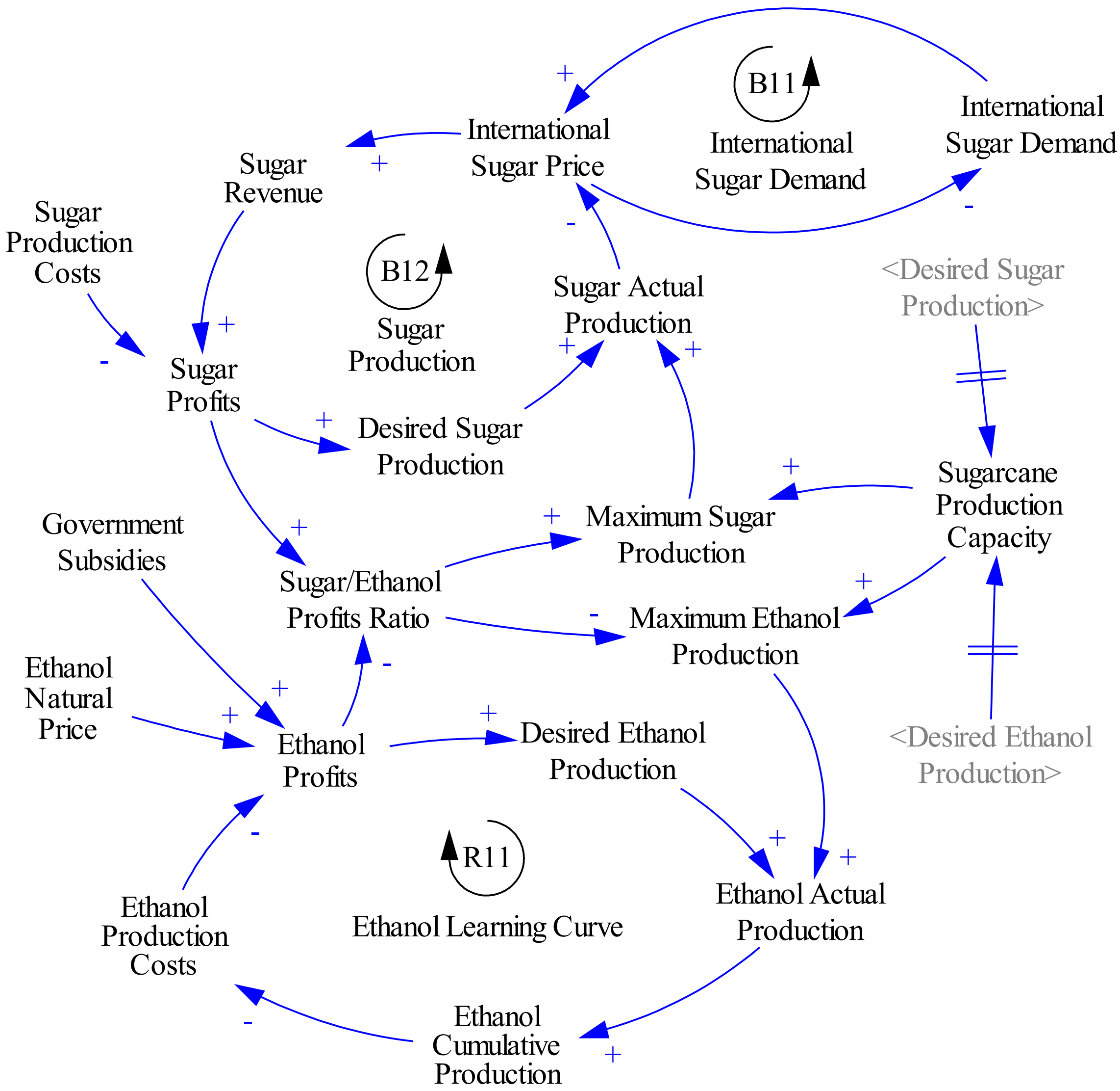


Figure 8 - Sugarcane Industry - Tragedy of Commons

The "commons" dynamics, as perceived now, are shown in the central part of diagram. Sugar over Ethanol Profits Ratio is a function of Sugar Profits and Ethanol Profits, which will be discussed later. An increase in Sugar over Ethanol Profits Ratio leads to an increase in Maximum Sugar Production and a decrease in Maximum Ethanol Production, since Sugarcane

Production Capacity is limited. At this stage a single criterion utility function of profits will be assumed. Note that Maximum Sugar Production summed with Maximum Ethanol Production should not be greater than Sugarcane Production Capacity (“commons” restriction).

Two loops close on Sugarcane Production Capacity. Those loops are omitted for clarity but the shadow variables show the causation. When Desired Sugar Production increases, Sugarcane Production Capacity increases through a delay (perhaps of one year). When Desired Ethanol Production increases, Sugarcane Production Capacity increases as well, also through a delay. The ethanol production capacity dynamics was omitted in the diagram, but it is an aspect that is to be included in the model, since there is a delay in capacity acquisition which can be relevant to show the sector dynamics.

Loop R11, Ethanol Learning Curve, is considered relevant to the second part of the research. This loop show how learning curve decreases ethanol production costs; in long term this will allow the ethanol industry to compete in price with petrol, even without Government subsidies. Starting from Ethanol Profits, when it increases, Desired Ethanol Production will also increase. An increase in Desired Ethanol Production will lead to an increase in Ethanol Actual Production. An increase in Ethanol Actual Production will increase Ethanol Cumulative Production. An increase in Ethanol Cumulative Production will decrease Ethanol Production Costs which will eventually lead to an increase in Ethanol Profits.

5 Conclusions and further studies

The first conclusion was that the system which emerged from the flex-fuel electronic injection technological innovation is very complex. Sterman (2000, p. 22) shows a set of causes that leads dynamic complexity to arise. In order to demonstrate that, Table 2 presents our perception of how this applies to the system studied.

Table 2 - Complexity of these Systems

Sterman's Criteria	System characteristics or example
Dynamic	Figure 9 shows the behavior over time of adoption in ethanol, gasoline and flex-fuel cars. This dynamics e adoption of a specific king of fuel showed, as well as its dynamics of change.
Tightly coupled	All subsystems interact between them, as well with other industries which will be included in other works
Governed by feedbacks	As shown in the Dynamics Hypothesis, there are several feedbacks loops which affect the system behavior.
Nonlinear	There are several relationships between system elements with non-linear behavior.
History-dependent	Most of the actions taken in this process are not reversible, some particular paths have been road and it is irreversible.
Self-Organizing	Dynamics between actors arise spontaneously; although, there was an external petroleum shock, that excited the system.
Adaptive	Capabilities and decisions change over time, an example was the decision of Brazilian Government to change its priorities due to a change in international petroleum price and the increase of in-country petroleum production.
Counterintuitive	Tragedy of commons is one example of this system which can be counterintuitive.
Policy resistance	End users decreased their confidence on ethanol supply due to a shortage and did not recover it, even after a long time.
Characterized by trade-offs	There are some examples of trade-off in this system: one is the Brazilian Government decision to tax the oil industry so as to incentive the ethanol production; and, in spite of an economic crisis, the Brazilian Government decided to invest in national oil industry, with remarkable results twenty years late.

Provided the positive consequences of the introduction of the flex-fuel electronic injection it can be concluded that Brazilian Government should have taken a policy to stimulate the development of this technology earlier. Perhaps this would allow a shorter delay between the first flex-fuel electronic injection available in the US in 1985 and 2003, year of first Brazilian flex-fuel car.

Another conclusion is that this study is, at least, 30 years later. The changes in loop dominance could have been planned and understood in-advance. Not as consequences of local decisions and shot-term vision. With this preliminary analysis, it is possible to understand the shift in loops dominance and why they happened.

In terms of innovation, it can be concluded that flex-fuel technology became a dominant design. Preliminary, it can be understood that it success was due to a change in consumer level of commitment of adopting ethanol or gasoline. This decision on using either ethanol or gasoline was postponed from the moment of buying a new car to the moment of refueling at the gas station.

In spite of being officially deactivated, Pro-alcohol program is now self sufficient and no longer need any subsidies. Since it will last for a long period with potential use of common resources with other industries, it can be concluded that these long-term effects should be studied in advance.

The next steps of this paper will be to build a simulation model so as to confirm (or reject) our dynamic hypothesis and to explore some scenarios and expand the boundaries of the model so as to include other relevant issues, such as land, food and environmental aspects.

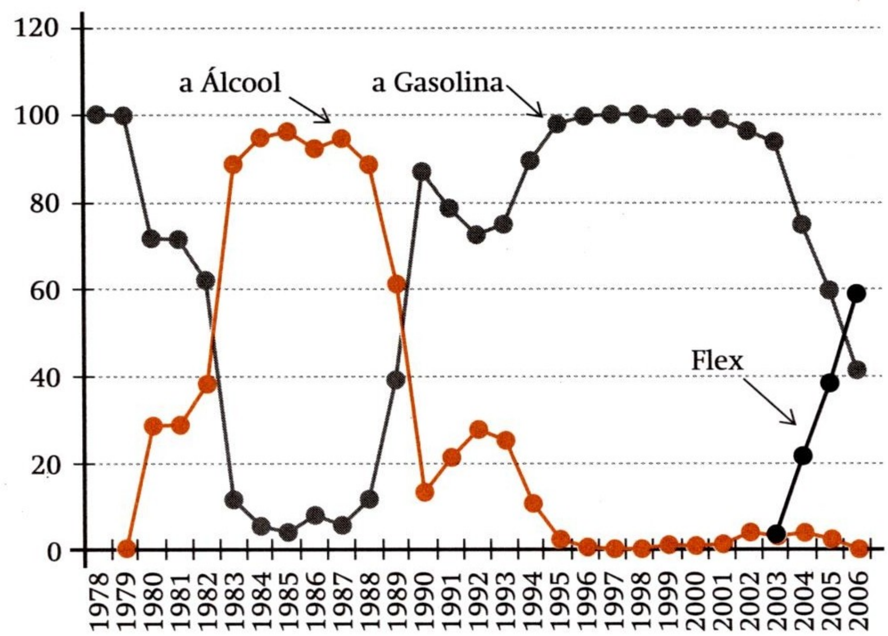


Figure 9 - Evolution of flex-fuel sales in Brazil (%)

Source: ANFAVEA, 2007

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