Modelling Ethanol Supply, Demand and Price in the Brazilian Macro Economy

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Abstract

The Brazilian program for sugarcane ethanol has been greatly successful since its inception about 40 years ago. But the road has been bumpy and today there are still major problems with price, supply and demand stability. This paper describes a research with the objective to propose policies by the government to stabilise and foster the Ethanol market in Brazil. The policies are tested by simulation. For that purpose a system dynamics model was built and calibrated to mimic the industry. Once the model is considered robust, it is used to test several proposed policies under different macroeconomic scenario forecasts. Historical evidence and the simulations suggest that the dynamics in the system are highly important in defining prices and other important variables. Shifts in sugar and gasoline prices have big short term and delayed influence in the ethanol market dynamics. The effects of long term dynamics are mixed with several short and long term cycles typical of commodities markets and the combination increases complexity exponentially. Simulation can be a crucial tool for understanding causality and planning sound policies for the medium to long terms.

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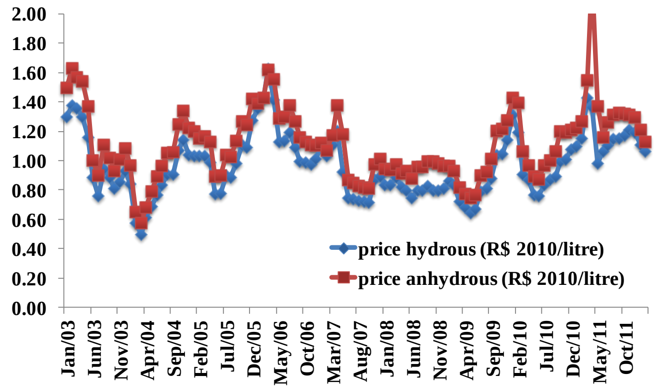
1. Problem and Purpose

In the 1970s Brazil started a national program for sugarcane ethanol. As the technology evolved, ethanol produced from sugarcane was added to gasoline in an increasing proportion (fixed by the government). In 1979 the industry started producing ethanol vehicles, boosting the market still further (Moreira & Goldemberg, 1999; Martines-Filho et al, 2006).

During the month of may in 2011 several reports on the news (Valor, 2011) in Brazil were discussing how ethanol prices had fallen more than 14% in the preceding three weeks. The drop was being followed by gasoline prices. Other reports (Infomoney, 2011) speculated that the big instabilities on price were expected to continue to happen on the coming years depending on the sugarcane harvest season if no "incentives" were given to the industry. Some weeks before, protests were taking place as fuel prices kept soaring to a record high. At least three editorial texts related to this crisis were found in one of the biggest newspapers in the country during this month, what shows how worried the public was with the problem (Folha de Sao Paulo, 1994-2012).

The volatility in prices was mentioned as a serious issue that leads to lack of trust in the energy matrix and undermines companies and consumers' confidence leading to a decreased level of investments which may affect the whole macroeconomic productivity and growth. Figure 1 shows the evolution of prices for ethanol since 2003, where the volatility is clear.

Figure 1. Ethanol wholesale prices evolution (R$ 2010/litre)



Source: CEPEA (2012), corrected with IGP-DI

Several causes for the instability in prices are mentioned, what shows how intricate the problem is: first there is a natural oscillation on sugarcane harvests; there are no big regulatory inventories; the demand has grown sharply; the fleet of "flex" cars (that run with either gasoline or ethanol) has grown greatly and is expected to keep growing; gasoline affects demand for ethanol and has a regulated price, with a big influence from the gigantic state owned Petrobras; sugar prices are rising (also oscillating) and that has a big influence on supply, as the mills can decide to produce either ethanol or sugar. The critiques in the media are obviously also directed towards the government and the lack of strategic planning for the sector.

The bio-fuel industry is considered highly strategic for Brazil, even after new oil fields were discovered. A considerable part of the goal for reducing greenhouse gases emissions in Brazil depends on the use of ethanol, as its production cancels out the vehicles emission due to carbon sequestration in the crops (Estadão, 2012). Concerns on sustainability, climate change and all the instabilities related to petroleum supply also contribute to increase ethanol's importance as an alternative fuel not only for Brazil but for many countries (Goldemberg, 2007). But even with this importance, the market has not being able to self regulate to a satisfactory level, and the supply is now threatened even for domestic consumption, not to mention for exports. In 2011 Brazil actually had to import a large volume of ethanol (CANAOESTE, 2011).

The problem with unstable supply and price volatility is highly complex. Ethanol itself is a commodity that behaves as other similar products, with a price being defined in a national market, the demand depending on several factors, mainly connected to economic activity and the supply depending on long term expectations of price and with long time constants. That would cause oscillations by itself, but apart from that this market also depends on other commodities such as gasoline and sugar, both also inserted in highly complex markets.

The particularities of the market in Brazil also pose several challenges. This industry has been heavily incentivized and subsidized in a recent past (Marjotta-Maistro, 2002). A previously regulated market had very different price setting mechanisms if compared to how it operates today. Previously consumers' decisions were made for the long term as one would either buy a gasoline or ethanol vehicle. Now cars are flexible and the decision on which fuel to use is done at the pump. This substitution completely changes the market dynamics. There is also an attempt to develop the market across the borders and that brings in new variables related to the competition from corn ethanol from the USA and other types of bio-fuels.

1.1. Approach to the problem

All the built in complexity and dynamic characteristics of these intertwined markets (ethanol, gasoline and sugar), make this a highly suitable problem to be approached using system dynamics. System dynamics is a discipline used to understand, model and simulate complex dynamic systems and to help generate policies to improve those systems towards desired behaviours. The theory was developed by Jay W. Forrester at MIT in the mid 1950s. First called Industrial Dynamics (Forrester, 1961), it evolved to System Dynamics as the theory incorporated a clear methodology, techniques and software to build models and simulate them and as it was increasingly applied to a wide range of problems (Forrester J. W., 1992; Radzicki & Taylor, 1997)[1].

Several studies of this market have been published but few consider the dynamics of supply, inventories and delays through the system and the short to long term trends on those variables. Because those dynamics can be highly important, System Dynamics has the potential to deliver a very innovative view on the problem. To build a comprehensive model that would satisfactorily simulate the market behaviour is a big challenge but potentially highly rewarding.

Different stakeholders might benefit from such a model like ethanol producers (to decide on when and how to invest or how to hedge), distributors (to decide on inventory levels), consumers (to plan ahead), Brazilian government (to define long term strategies for the industry and the whole energy matrix). Because a system dynamics model would have several possible uses, this study focuses on the Brazilian government (or the Energy Secretary) as a client. The concrete objective is to generate recommended policies for the government to stabilize and foster the ethanol market in Brazil by developing a calibrated system dynamics model of the related industries and simulating it against possible policies and macroeconomic scenario forecasts. The model should explain how and why ethanol production and prices have evolved as they did in the past and should simulate possible future scenarios for the market.

This report is organized as follows: section 2 presents a comprehensive definition of the market, variables of interest, related industries, players etc. This section also discusses

[1] For a thorough introduction to System Dynamics see Sterman (2000).

the problem, its causes and consequences more deeply; section 3 presents a review of selected studies with approaches to the problem (mainly econometric models) while discussing their shortcomings and how this research seeks to make a contribution. Section 4 presents the model structure divided by each sector, with explanations of the variables, hypothesis, assumptions etc. Section 5 describes the model behaviour and calibration process. Section 6 will use the calibrated model to analyse possible policies under different scenarios and to give recommendations based on the analyses. Finally, section 7 will present the conclusions, limitations of the model and suggestions for continued research.

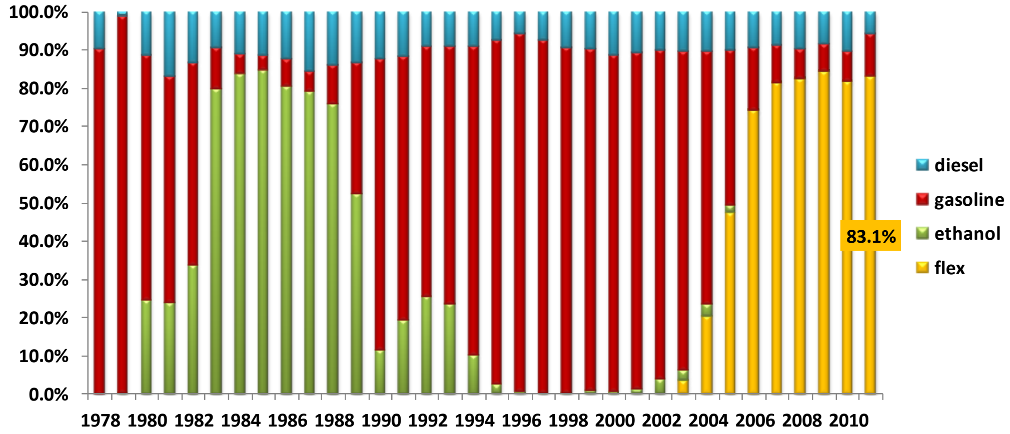
2. The Ethanol market

Brazil has produced sugarcane since the 17th century and sugar was the country's first large scale economic activity. In the 1970s, as a response to rising oil prices, the National Programme for Ethanol (PROALCOOL in Portuguese) was launched to promote the use of ethanol as an alternative fuel (Moreira & Goldemberg, 1999).

2.1. Demand

Ethanol is used in two forms: hydrous ethanol is used purely in vehicles designed specifically for this kind of fuel, while anhydrous ethanol is mixed with gasoline. In the beginning of the PROALCOOL, ethanol was used exclusively as the anhydrous variety. In 1979 the first ethanol vehicles (that run on pure hydrous ethanol) started being produced and demand for ethanol soared throughout the 1980s. But the market for ethanol vehicles did not hold (see Figure 2).

Figure 2. Distribution of vehicles licensed in Brazil by fuel type from 1978 to 2011



Source: (ANFAVEA, 2012)

The demand for ethanol cars diminished drastically at the beginning of the 1990s and was practically nonexistent by the middle of the decade. The reasons for the slash on demand are various. Martines-Filho et.al (2006) mention the lower price of oil and a change in government policy as possible causes. Goldemberg (2008) mentions lack of guarantee for the ethanol supply and a shortage in 1990 that ignited a crisis. One can also speculate that the market was being sustained only by heavy incentives that were cut when economic conditions became adverse.

Regardless of this specific case, any attempt to interfere with markets like this carries the challenge of convincing consumers to shift and suppliers to invest. Consumers have to trust on the long run stability of the supply and prices and suppliers have to trust there will be demand. The process has to be kick started, most probably by the central government, but this promotion is expected to be difficult, expensive and prone to failing. Sterman (2010) shows this type of problem has happened in different countries for similar reasons. Keeping the market confident is not an easy task when it is being sustained by heavy subsidies that may disappear eventually.

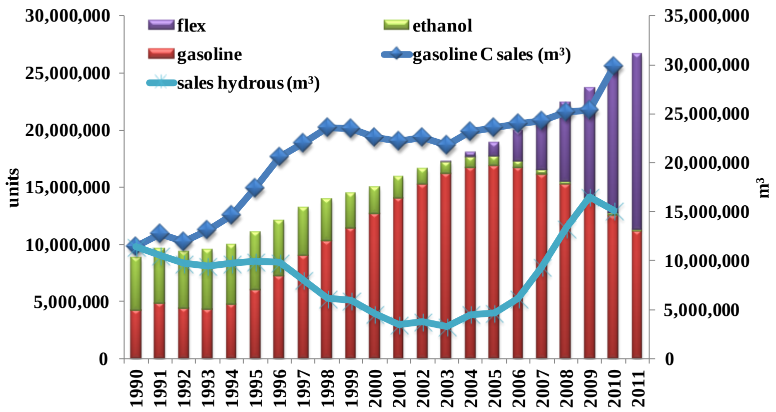
This challenge was overtaken later on in Brazil with the introduction of the flex-fuel vehicles. Flex-fuel is a new technology that allows vehicles to run with any blend of gasoline and (hydrous) ethanol (Goldemberg, 2008). That eliminates the trust issue: if the price and supply for ethanol are unstable the consumer can immediately shift to gasoline. The decision is now made at the pump each time the tank needs to be topped up. There is no more long term commitment to one single fuel.

The results have been highly positive (see Figure 2). The demand for flex-fuel vehicles soared throughout the 2000s. By the end of 2011, more than 80% of all vehicles sales were of flex-fuel (close to 90% for light vehicles) and they already represented more than 50% of the total fleet, which contributed to further fuel the ethanol and sugarcane market.

It is important to point out that a large fleet of flex vehicles does not necessarily translates into high demand for ethanol as these cars can run on 100% gasoline[2]. With the consolidation of flex cars on the fleet, the demand for hydrous ethanol will be fundamentally connected to that of gasoline and the relative price of both fuels will steer the demand. Ethanol delivers ca. 70% of the efficiency of gasoline, hence the consumer should expect a proportionately smaller price (per volume) for it (Ferreira et al, 2009).

Figure 3 shows the Brazilian fleet for non-commercial vehicles[3] and fuel sales (assumed equal to consumption). It suggests that hydrous ethanol consumption is not entirely related to the size of the flex fleet (see year 2010, for instance).

Figure 3. Brazilian fleet by type and fuel sales (1990-2010)



source: (ANFAVEA, 2012); (ANP, 2011)

It is also visible that consumption can decrease even with a growing fleet as around the years 2000 and 2001. Those years saw a considerable increase in prices which influenced the demand negatively. Together with prices, income can also have an important influence on consumption (Dahl & Sterner, 1991).

Another important parameter is the average efficiency of the vehicles (e.g. in Km/litre). The higher the efficiency the lower the consumption (Schünemann, 2007). Technology can play an important role in reducing the average consumption. Also the average age of the fleet can have an impact, as new cars tend to be more efficient. In that sense, economic growth could actually contribute to the fleet renovation, decreasing the average age and improving average efficiency which, ceteris paribus, would actually reduce consumption (a counter-intuitive result).

The parameters discussed so far are concerned with the increase in hydrous ethanol consumption. Nevertheless the demand is not exclusively driven by hydrous ethanol. An important chunk of the demand comes from anhydrous ethanol which has to be mixed to gasoline in a proportion fixed by the government. That demand kept the mills running even when the fleet of ethanol vehicles shrunk. The government actually uses this ratio as an instrument to regulate the market.

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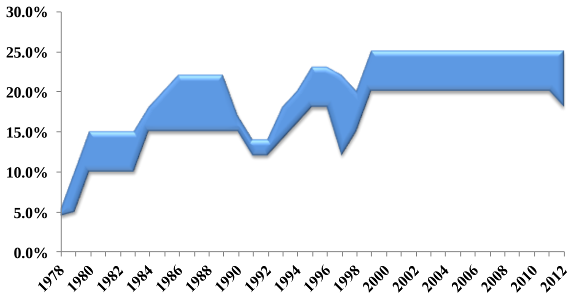
[2] That is gasoline "C" which contains added anhydrous ethanol. Gasoline C is also commonly called Gasohol (Freitas & Kaneko, 2011).

[3] The fleet is a rough estimate based on data for the number of licensed vehicles of each type per year (ANFAVEA, 2012) and considering an average life of 14 years, after which the cars are scrapped. The results for the years 2009 and 2010 are close to the estimates from ANFAVEA itself. The governmental agency DENATRAN also provides fleet data but they are overly inflated with very old licensed vehicles that are probably scrapped since many years (Losekann & Vilela, 2010).

Figure 4 shows how the share of anhydrous ethanol has evolved since 1978. Data on this share is not completely clear on official records (ANP, 2012) and it can vary within a single year, so the chart shows an approximate range of possible values at each point in time[4]. In 1990, for instance, after a shortage crisis, the share of anhydrous ethanol was slashed from close to 22 to 12%.

Figure 4. Fraction of anhydrous ethanol added to gasoline



source: (Macedo & Nogueira, 2004); (ANP, 2012); (Folha de Sao Paulo, 1994-2012)

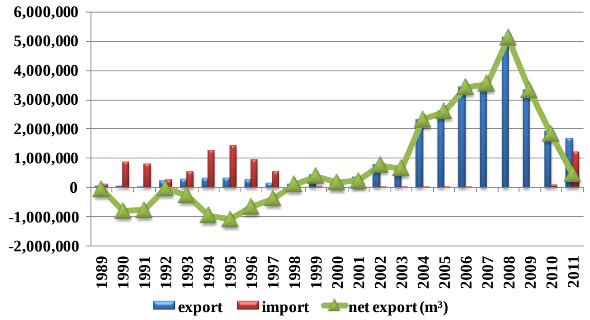
The same happened in 1996. At the end of 2011 there was another threat of shortage and the proportion was cut from 25 to 20%[5] while at the same time the stipulated minimum amount was cut from 20 to 18%, indicating the possibility of additional cuts in the future.

While it can be a good mechanism to adjust demand and avoid shortage crisis in the short run, the control by the government can also be dangerous to the market if it sends wrong signals. In 1996, for instance, after the big cut in the ratio of anhydrous ethanol, the industry replaced it with MTBE (Methyl tert-butyl ether) as an additive to gasoline. Before that Methanol had also been used. The replacement raised a big concern that it would be permanent (Leite, 1996). This type of concern may trigger a crisis in the industry as investors gradually lose trust on the stability of future demand and, because of this lack of confidence, the market forecasts lower capacity and a bigger necessity to shift to substitute products (a self-fulfilling prophecy). The demise of the market may be the result of confidence erosion on both sides feeding a reinforcing feedback loop.

Fortunately for the industry that did not happen in Brazil. Anhydrous ethanol was consolidated as the gasoline additive and the demand for hydrous ethanol was revived with the flex-fuel vehicles as discussed before. The last, and of increasing importance, chunk of demand comes from net exports.

The industry was seeking to expand abroad and that indeed happened along the 2000s (see Figure 5). But starting in 2009 the exported volume shrunk and the country had to import a large volume in 2011.

Figure 5. Exported and imported ethanol in cubic meters (1989-2011)



source: (Brazil, Ministry of Agriculture, 2007); (CANAOESTE, 2011)

The slash in exported volume did not happen only due to diminishing external demand (even though the appreciation of the real did make it more expensive), but mostly due to a shortage in supply where the important bottleneck is located now.

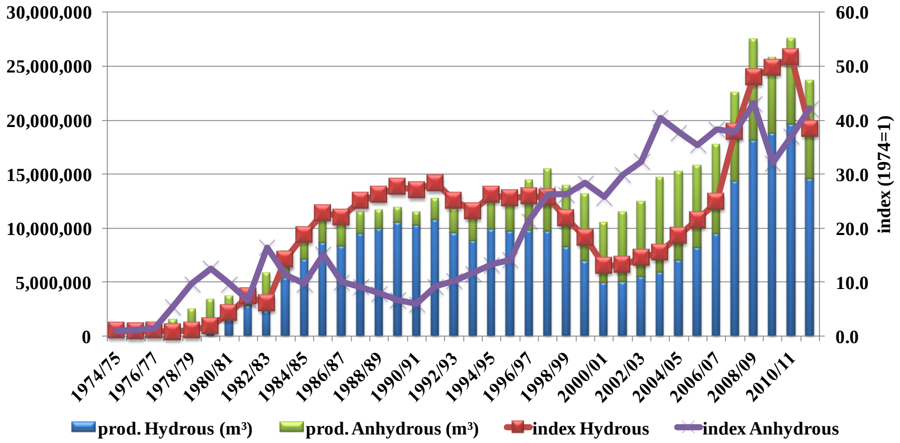
[4] For the current gasoline engines there is a limitation of about 25%, above which the engines would be damaged.
[5] http://www1.folha.uol.com.br/mercado/967193-mistura-de-etanol-cai-para-20-a-partir-de-1-de-outubro.shtml

2.2. Supply

The production process starts with the sugarcane harvest. Once harvested the sugarcane is perishable and has to be transported and crushed rapidly, otherwise it will lose its usable sucrose. The harvest can be manual or mechanical. Manual harvests require that the crop be burnt beforehand. There is a trend in Brazil to replace most of manual harvests, at least in the south-central region. Once it arrives at the mill, the sugarcane is washed and crushed. The juice can then be destined for sugar or ethanol production. For the ethanol process the first product of the fermentation is hydrous ethanol which contains 4% more water than anhydrous ethanol. Hydrous ethanol is then dehydrated to produce anhydrous ethanol with 99.6 Gay-Lussac (GL). The whole production process takes about one day (UNICA, 2012).

Figure 6 shows the evolution of the total production of hydrous and anhydrous ethanol. The lines represent indices relative to the 1974 production. By 2011 production of both types had grown about 40 times, showing a considerable success of the program.

Figure 6. Ethanol production by type and indices (1974 to 2011)[6]



source: (Brazil, Ministry of Agriculture, 2007); (UNICA, 2012); (CONAB, 2011)

In the beginning the curves show how the anhydrous variety starts ahead until the pure ethanol vehicles start pulling the demand for hydrous ethanol. The production of the hydrous variety then grows substantially but with diminishing strength until the beginning of the 1990s when the demand from ethanol vehicles halts as we saw previously. As the pure ethanol vehicles gradually leave the fleet the production of hydrous ethanol plummets, but the fall in total production is not so abrupt thanks to the demand for anhydrous ethanol that is now being added to gasoline in a proportion bigger than 22% after 1996 (see Figure 4).

The production of hydrous ethanol then recovers from the beginning of the 2000s with the introduction of flex-fuel vehicles and also with the growth in exported volumes (Figure 2 and Figure 5). But then again in 2011 there is a major fall in hydrous ethanol production. The fall is caused by a bottleneck in supply and not by lack of demand. As the inventories deplete, the market price for hydrous ethanol starts increasing and the demand responds fast due to the flex vehicles.

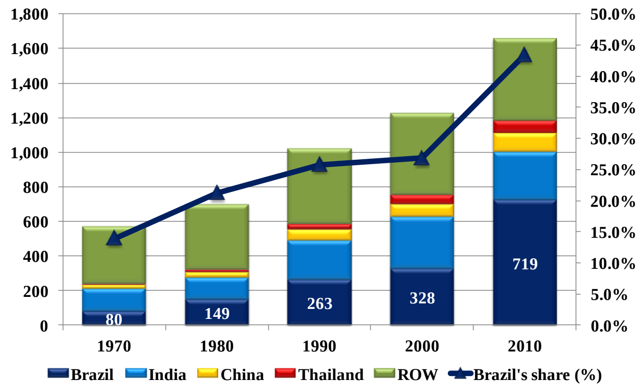
Curiously, as the demand for hydrous ethanol falls, the demand for anhydrous ethanol grows proportionately via the increased demand for gasoline (ANP, 2011). This

[6] Time is shown in harvest seasons instead of years. The season starts on April of the first year and ends on march of the next.

mechanism creates a localized reinforcing dynamic: the bigger the hydrous price, the lower its demand and the higher the demand for gasoline and anhydrous ethanol, which drains yet further the hydrous inventory and further pressures its price. The ethanol prices were pressured since 2010 and on top of that the production fell considerably in 2011, which lead to an even bigger pressure and a massive migration of the consumption to gasoline. But what is causing the drop in supply?

The total sugarcane production in Brazil has grown nine fold since 1970 and especially in the last decade. By 2010 Brazil was the largest global producer, accounting for more than 40% of worldwide production (see Figure 7). The increase in production is the result of both an increase in the harvested area and in productivity.

Figure 7. Worldwide sugarcane production (million tons)

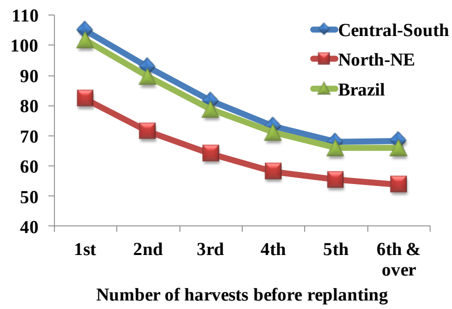


Source: (FAO, 2012)

Productivity depends on technology, on random factors (especially weather) and on the average age of the crop. Technology is related to the accumulated learning, or the experience curve (Bake et al, 2009) and its expected effect is to continually increase the productivity with time (knowledge can also depreciate, but presumably very slowly). But the aging and random effects may cause the productivity to oscillate.

Sugarcane can be harvested several times before it has to be planted again. On average the replanting takes place every 6 years in Brazil (Andrade, 2012). If it is replanted often it will potentially yield a higher productivity. Figure 8 shows an estimate of land productivity varying negatively with the age of the crop. The total average productivity on this setup was 81.4 tonnes/ha.

Figure 8. Land productivity according to crop age (tonne/ha)



source: (CONAB, 2008)

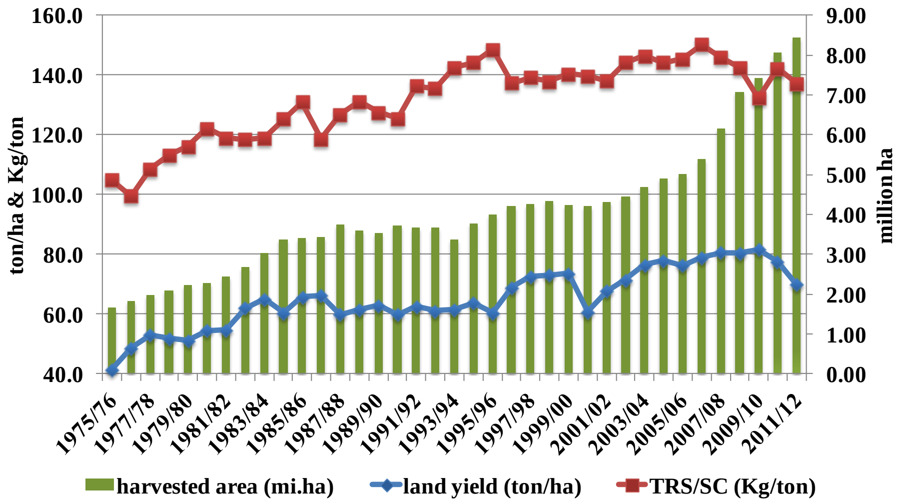
The chart also shows different curves for the north-northeast and central-south regions. The south is more technologically advanced and has better climate, which translate into a considerably higher productivity. By 2010 the central-south region was responsible for ca. 86% of the area and 90% of the sugarcane production in Brazil (CONAB, 2011).

The maximum theoretical productivity is 280 tonnes/ha/year (Duke, 1983) which means that there is still room for improvement. Nevertheless, for the 2011/12 harvest the forecast for land productivity was lower than 70 tonnes/ha in the central-south region, a drop of almost 20% relative to the historical average. The drop was attributed to the aging of the crops and bad weather conditions (CANAOESTE, 2011).

Apart from the land productivity there is also the sugarcane productivity. Once harvested the sugarcane may yield different amounts of usable sucrose to be transformed in sugar or ethanol. This exploitable amount is called Total Recoverable Sugar (TRS)[7]. TRS also depends on technology, or the experience curve (Goldemberg, 2008) and the yield has grown considerably since the inception of the PROALCOOL: from less than 100 Kg per tonne of sugarcane in 1977 to close to 150 Kg/tonne in 2006/07 (UNICA, 2012). But this yield too can oscillate and it has been falling in the last years.

Figure 9 shows the evolution of land used by the sugar and ethanol industry and the calculated productivities (land yield and Kg of TRS per tonne of sugarcane). The curves are roughly estimated as they gather data from different sources. The harvested area used by the sugar and ethanol industry in recent crops are available from the National Supply Company (CONAB, 2011)[8]. The land use for previous years was estimated based on the yearly growth rates provided by FAO[9]. Production data is available from the Ministry of Agriculture and UNICA.

Figure 9. Land use and productivity (1075-2011)



source: (Brazil, Ministry of Agriculture, 2007); (UNICA, 2012); (FAO, 2012); (CONAB, 2011)

The curves show a long term gain in productivity, but apparently there is a persistent loss in land and sugarcane productivity in the last years. The aging of the crops and the influence of the weather have been extensively mentioned in reports accounting for the lost productivity (CONAB, 2011). The weather is exogenous to the system, but the aging crops may be caused by the system itself (lack of investments, pressure to produce etc.).

Another important factor determining supply is the mills capacity, or the total capacity for processing sugarcane. Most of the capacity in Brazil is from multipurpose mills, that is, they can produce both sugar and ethanol. Another particularity is that the Brazilian mills own a big share of the sugarcane crops (typically close to 70%) so the supply chain is strongly integrated (CONAB, 2008).

In the 2007/08 season a total of 343 units offered a total capacity of 551 million tons/year of which 88.6% were in use (CONAB, 2008). By 2012 there were 425 units

[7] In Portuguese the term is ATR (*Açúcar total recuperável*)

[8] There is also data available from INPE/CANASAT (CANASAT, 2012) obtained from satellite monitoring from 2003 to 2011 (for the central-south region only) but the area is inflated, probably considering all sugarcane not related to the sugar/ethanol production.

[9] FAO data on land and production is also inflated with sugarcane not related to the sugar/ethanol industry.

with a total capacity close to 700 million tons/year of which 16% were idle (Brazil, Ministry of Agriculture, 2012).

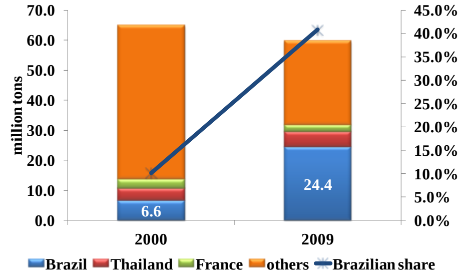
Another possible explanation for the drop in production is that the total mill capacity did not grow as expected since 2008 after the global crisis that affected investors in the industry (Jank, 2011). It is possible that the area being actually harvested is smaller than the total area available (despite the mills' idleness rate). The effects of the crisis could also be responsible for the aging of the crops and lost productivity due to reduced investments.

2.2.1. The sugar market

Together with the sugarcane yield and the mills capacity, demand for sugar is fundamental in defining the supply for ethanol. Sugar is a direct competitor for raw materials and capacity. For the mills the decision to produce one or the other is quite flexible. All they have to do is to divert the sugarcane juice to one or the other process (Moreira & Goldemberg, 1999).

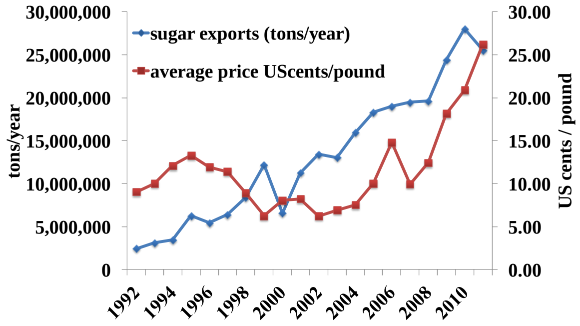
Brazil has vastly increased its sugar production in the last decade, mostly for the foreign market as its domestic consumption only grows slowly with the population. From 2000 to 2009 the exported volume grew almost four times and the share went from 10 to more than 40% (Figure 10). The growth in exported volume in the last years has benefited from an upward trend in global prices (despite the appreciation of the real). Figure 11 suggests that the global market is growing and putting pressure on prices, which also puts pressure on the sugar production, diverting raw materials and capacity from ethanol. It is also apparent that Brazil has now a big influence in the global sugar price. In 2011, for instance, the drop in production seems to have caused the prices to increase even more than the previous trend indicated.

Figure 10. Worldwide volume of exported sugar.



Source: (FAO, 2012)

Figure 11. Brazilian exported volume of sugar and global prices

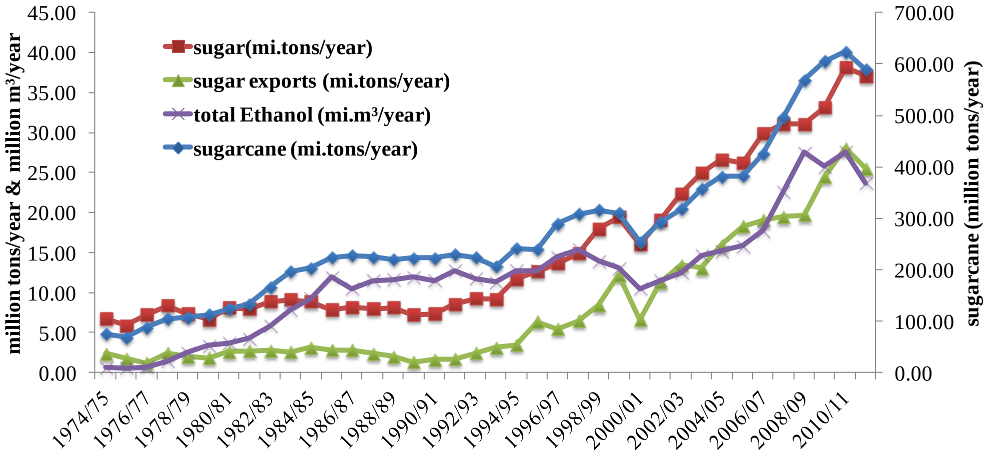


Source: (FAO, 2012);(Index Mundi, 2012)

The combined effect of the land use, productivities, supply of sugarcane and demand of sugar and ethanol are summarized in Figure 12. Apparently the forces driving the enormous growth in sugarcane production are the global demand for sugar and the local demand for ethanol fuelled by the flex vehicles.

In the last three years, ethanol production stopped growing and all the extra sugarcane is being absorbed by the global sugar market. In 2011 the situation gets even worse with a drop in production (due to the decreased productivity as we saw previously) and then even the exported volume of sugar falls despite the high prices.

Figure 12. Production of sugarcane, sugar and ethanol (1974-2011)



source: (Brazil, Ministry of Agriculture, 2007); (UNICA, 2012); (FAO, 2012)

2.3. Costs

The costs to produce ethanol and sugar have dropped considerably since the inception of the PROALCOOL program. Goldemberg et.al. (2004) use the learning cuve concept to analyse the cost reduction from 1980 to 2002. They found that the progress ratio for the prices in US dollars was of 93% until 1985 and 71% until 2002. That means that costs were being reduced in 29% for each doubling of cumulative production.

Bake et.al. (2009) use the same concept to assess cost reduction but they separate feedstock (the sugarcane production) from industrial production costs, which, according to the authors, "would provide more insights into the factors that lowered costs in the past" (page 645). The authors find a progress ratio of 68% for the feedstock and 81% for the industrial costs from 1975 to 2004. According to this study the costs to produce ethanol were US$340 per cubic meter in 2004 and could reach between US$200 and US$260 per cubic meter in 2020.

It makes sense to analyze the agricultural costs separately as they have different drivers if compared to industrial costs. The feedstock costs depend mainly on the productivity indices (discussed previously) while industrial costs depend on scale and other learning effects (cost of capital, automation etc.).

Another important technological development is in the use of self generated electricity from the bagasse (the residual from the sugarcane crushing process). Currently the mills produce large amounts of electricity from the bagasse. There is actually a surplus that is sold to the grid increasing the mills potential turnover with yet another byproduct. The generation potential is actually much bigger than used today as new technology may allow the use of the tops and leaves (also called SCAR - Sugarcane agricultural residues) to yield another one third of the energy content per tonne of sugarcane (Pippo et.al., 2011).

A comprehensive research with real costs observed by the producers is published annually by PECEGE/CNA (PECEGE, 2011). A summary of the results for the 2010/2011 harvest is shown in Table 1. The research was done for the central-south region only, so an estimate for the northeast participation was added (the NE region is assumed to have a cost 22% higher (PECEGE, 2009) and 11% participation on the output).

Table 1. Summary of ethanol production costs (2010/11)

Costs for Hydrous ethanol ($R\$/m^3$)						
Area	Traditional	Expansion	Central-south	NE	Brazil	
Sugarcane	565.10	520.28	551.65	673.02	565.00	61.0%
Industrial costs	247.42	249.02	247.90	302.44	253.90	27.4%
Overhead	103.78	104.88	104.11	127.01	106.63	11.5%
Total cost	**916.30**	**874.18**	**903.66**	**1,102.47**	**925.53**	
fixed costs	318.31	344.44	326.15	397.90	334.04	36.1%
share:	70%	30%	89%	11%		

source: (PECEGE, 2011) plus author estimates

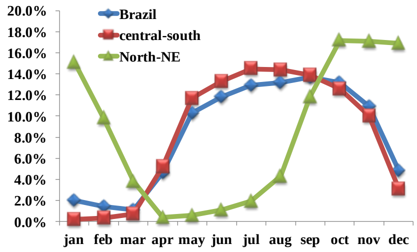
The study shows increasing costs from the 2007 to the 2010 harvest, which seems contradictory to the aforementioned studies on experience curves. The probable explanation is the loss in productivity discussed in section 2.2. Considering an average cost of R$51 per tonne of sugarcane and the land yield of 77.45 tonnes per ha in the 2010/11 harvest we reach a cost of approximately R$4K per ha. This cost will probably vary slowly, while the productivity oscillations will dictate the variations in the total cost.

2.4. Seasonality and prices

All the dynamics of the fuel and sugar markets discussed so far become yet more complicated when we look at the production data through the year.

Sugarcane is seasonal and the harvest is mostly done during the dry months. In the central-south region the season is from April to November and in the north from September to March. The combined distribution for the country is very close to the one for the central-south region as it dominates production (see Figure 13).

Figure 13. Fraction of sugarcane volume harvested each month

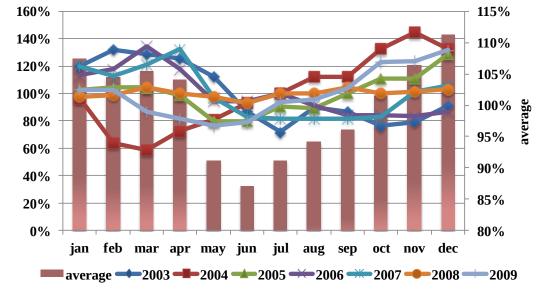


Source: (CONAB, 2010)

This seasonality has an influence on price, though its magnitude is uncertain. The big oscillation in prices was presented before in the introduction (see Figure 1).

Figure 14 shows how the prices behave through the year relative to the year average. In some years like 2004 the behaviour is unconventional, but if we take the average of all years it seems that the price tend to be higher when the harvest ceases and the inventories start depleting.

Figure 14. Price of hydrous ethanol each month related to the year average



source: (UNICA, 2012)

A plausible hypothesis for the price behaviour is that it responds to the dynamics of supply and demand via a perceived inventory coverage as is common for commodities (Sterman, 2000). If the level of inventories depletes or grows slower than demand the coverage will start falling. With time the agents in the market perceive this gap and respond by increasing the price (or vice-versa). The size of the gap will depend on a reference value, which can change with time as the economic agents adjust expectations. In this specific market the reference value will probably vary with the season. It is fair to assume that the market will expect a higher level of inventories at the end of the harvest and a much smaller level at the beginning of the next harvest after months of very little production. The cost should also have an influence on the price, especially in the long run. This issue will be further explored on the model development.

Government intervention can be equally important in determining prices. Up to the 1990s ethanol and gasoline prices were fixed by the government. The sector was gradually deregulated until 2002 when all prices, including gasoline, were (in theory) set free to adjust to market dynamics (Marjotta-Maistro, 2002). Consequently the price adjustment theory described previously would not hold before 2002. In other words, a model with this hypothesis might describe the market after the deregulation, but would be moot to explain the dynamics before that. Furthermore, gasoline prices are set free in theory only, as pointed before, because the government has a big influence in Petrobras and can still "indirectly" control gasoline prices. The model analysis will show that this control can have a crucial influence in ethanol prices likewise.

2.5. The road ahead

In February, 2012 the ministry of agriculture published a note communicating the government plan to revamp the sector (Brazil, Ministry of Agriculture, 2012). The plan consisted mostly in the financing of sugarcane production with an estimated spend of R$60 billion in 3 years.

The concrete actions involved renovating a large part of the crops in order to increase the productivity (it is mentioned that now the average age of the crops was over the 6th harvest in a large area) and expanding the total crop area.

The government also planned to establish a line of credit to be invested in storage capacity so the mills can increase inventories in order to smooth the supply between the harvest seasons. The policy aimed at creating regulatory stocks belonging to distributors, though they eventually would still be physically located within the mills (Folha, 2011).

The industry estimated that an investment of R$156 billion would be necessary until 2020 in order to increase production to 1.2 billion tonnes of sugarcane and attend the expected demand for sugar and ethanol (Valor, 2011). One concern related to this expansion is on the available land and the constant threat that the crops will occupy environmental protection areas. The industry claims that all the expansion up to now has been using pasture land and that the delocalized cattle has increased its density instead of (as feared by environmentalists) moving to the north and accelerating deforestation (Goldemberg, 2008).

A potential solution for the land issue is the second generation ethanol. With this technology, ethanol can also be produced from the bagasse, which today is used only for electricity generation. The yield of one tonne of sugarcane can almost double and that should add to the capacity without demanding more land.

As for the demand, the internal demand for hydrous ethanol has shrunk with the higher prices, but because the fleet of flex vehicles keeps growing, it can be easily resumed once the prices fall back. The industry may face a drawback with external demand though, as the shortage crisis on the last years may have reduced potential buyers' confidence. Nevertheless there is an ongoing effort, mainly from Brazil and the USA, to create a global market for ethanol in which case anhydrous ethanol would become a global commodity with a global fixed price. That would probably foster the Brazilian export potential.

In summary, the current crisis in the industry can be solved with technological development and with more investments, including resources from the tax payers, in order to boost supply. But the government policy related to the sector may seem dubious: on one side there are announcements of sizeable investments in the ethanol industry, but on the other hand Petrobras (a public company under heavy influence of the central government) keeps gasoline prices artificially low (Folha, 2012), which has a negative effect on the ethanol market. One concern is that the current public policy may not be particularly interested in fostering the ethanol industry in the long run, but is just using both fuels as instruments to control inflation in the short run.

At this point we hold this discussion and move ahead with the presentation of related research and then with the development of the model. The issues raised insofar will be further discussed as the model is built, calibrated and analyzed.

3. Literature review

Demand for fuel, especially gasoline, is a widely explored subject. Dahl & Sterner (1991) survey more than one hundred studies using econometric models to explain gasoline demand. All the models specify gasoline price and income as determinants for the demand and calculate the elasticity for each of these variables. Models may be static or dynamic (considering lagged endogenous effects, that is, the demand at one period depends on the demand in the previous period). They also differ on which variables other than price and income are included (such as fleet, characteristics such as efficiency, price of vehicles and substitute fuels etc.) and type of data (periodicity and time series versus cross-sectional data).

The authors find that data periodicity of less than a year is subject to seasonal effects and tend to be less reliable. They also find that the estimated elasticity differs between short and long terms but not significantly within these categories, hence it was possible to find an average value for each. Price elasticity was -0.26 for the short run and -0.86 for the long run, and average income elasticity was .48 for the short run and 1.21 for the long run. The authors also find that simple static models tend to measure short run price elasticities and models using cross-sectional data tend to measure long term effects. An important conclusion is that the long run elasticity, both to prices and income, is large, so economic growth and policies such as tax on fuels will both have a big effect on demand in the long run.

Ethanol and gasoline demand and prices in Brazil have also been extensively studied. Most publications also use econometric models. The period used for analysis is highly important for the results as the market went through a fundamental change in the late 1990s and beginning of the 2000s when prices were deregulated. Another crucial change was the introduction of flex-fuel vehicles in 2003, which dramatically altered the substitutability between gasoline and ethanol. Marjotta-Maistro (2002), for instance, finds that gasoline and ethanol prices show little response to market dynamics during the period of government intervention. Alves & Bueno (2003) model the relationship between gasoline and ethanol and assess the cross elasticity of ethanol prices in gasoline consumption. The authors find that the cross elasticity is small, suggesting low substitutability, which should be expected since the data refers to a period before the introduction of flex-fuel vehicles when the decision on which fuel to use was made for the long term.

More recent research using data from the period after 2003 when the flex vehicles were introduced, find that the price of gasoline has a big influence on ethanol demand (Freitas & Kaneko, 2011) and on ethanol prices (Ferreira, Prado, & Silveira, 2009); (Rodrigues, 2009) or that demand for gasoline is influenced by the ethanol price (Silva, Tiryaki, & Pontes, 2009). Freitas & Kaneko (2011) provide a good summary of studies on the demand for gasoline and ethanol in Brazil. The authors also develop their own econometric model and find that ethanol demand is highly elastic to the prices of ethanol and gasoline, apart from the fleet size. But curiously they find that income has no significant influence in demand.

Most studies are concerned with demand and prices only and typically disregard supply, meaning that supply is assumed not be a constraint. Consequently, the models typically disregard sugar price and demand as determinants of ethanol prices. Bacchi (2005) is an exception. The author finds that sugar prices influence ethanol prices but with small elasticities.

Studies found on ethanol supply are mostly descriptive and have been cited in section two. Those include several reports from government agencies such as ANP (regulatory agency for petroleum and natural gas), CONAB (national supply company) and the Ministry of Agriculture, or organizations such as UNICA (private association of sugar and ethanol producers). Costs to produce ethanol and the experience curve, on the other hand, have been more thoroughly studied (Goldemberg et.al., 2004); (Bake et.al., 2009) and the present work builds on some of the related conclusions.

There seems to exist a gap on the studies, especially on what concerns coupling supply with demand and on the impact of the sugar market dynamics. There is also a lack of studies concerned with the long term development of the industry. Econometric models are typically more concerned with short term effects and have to rely on historical data as inputs, while system dynamic model are usually concerned with more long term effects, and with defining an endogenous structure based on knowledge of the system that do not necessarily must rely on existing data (Meadows, 1980). Freitas & Kaneko (2011), for instance, mention limitations in data as one of the criterion influencing the methodology choice.

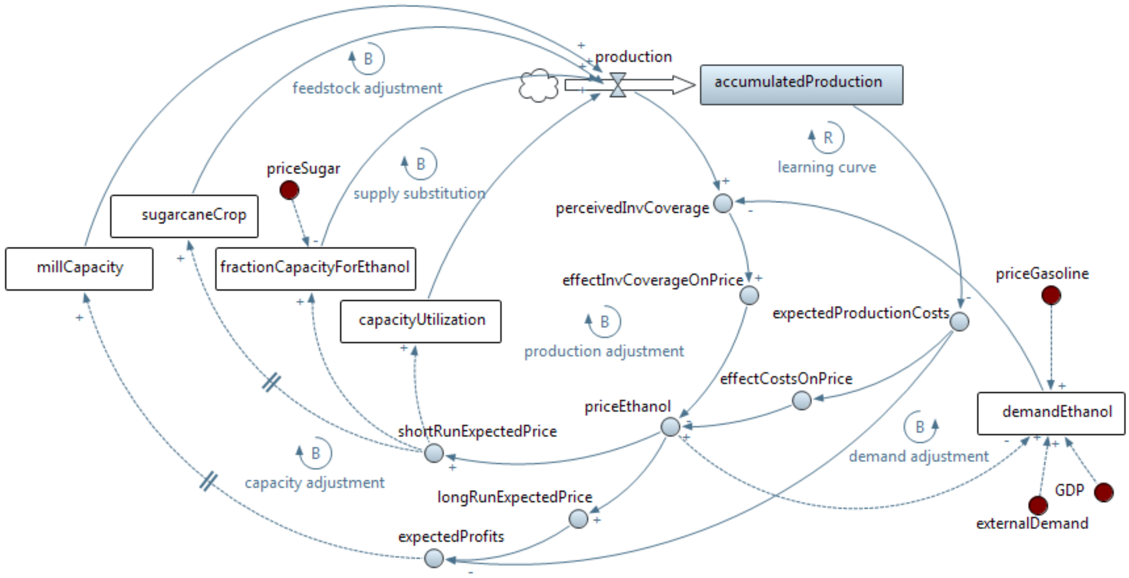
The present research chooses a quite different approach to study ethanol demand and prices if compared to the aforementioned econometric studies. Supply is considered vital in determining prices, especially for the long term, and so are the prices and demand for sugar and gasoline. Variables such as costs and productivity are determined endogenously to a great extent and also have dramatic effects on price and demand for ethanol.

Several studies have been published using system dynamics to model commodity markets (Sterman J. D., 2000; Taylor, 1999), petroleum supply (Davidsen, Sterman, & Richardson, 1990) and transportation policies (Fiorello, Fermi, & Bielanska, 2010), but the author is unaware of any other previous study of the ethanol market in Brazil that attempts to model demand and supply coupled with other variables related to sugar and gasoline, costs, productivity and capacity in one single endogenous model. The remainder of the report describes this exercise.

4. The Model

The core of the model consists of the dynamics of the price of ethanol controlling the equilibrium of supply and demand (see Figure 15). The price responds to cost variations and to the inventory coverage, which captures the relationship between supply and demand at each point in time. Many of the concepts related to price and capacity have been adapted from a generic commodities model in Sterman (2000), pages 798 to 824.

Figure 15. Overview of the model



The white boxes in the diagram represent different sectors, or submodels (not stocks) which will be explored moving forward. This first high level diagram is a simplification to convey the general structure and present some important feedback loops.

On the demand side there is a balancing loop called "demand adjustment": as the demand grows, inventory coverage decreases (at least until production catches up) and pushes prices up, which will counteract the initial movement and bring demand down again.

On the supply side, four balancing loops control capacity or the capacity use: if the price increases, the short run expected price will increase and that will trigger the mills to either increase utilization or increase the fraction of capacity used to produce ethanol (instead of sugar) or plant more sugarcane. On the long run, a consistent growth in prices will also increase the expected future profits and induce the producers to invest more on capacity. The changes in utilization and fraction of capacity to ethanol are relatively fast, while planting more sugarcane is slower (at least one year) and investing in new capacity is much slower (at least four years for a new plant to be built).

There is also one important reinforcing loop in the diagram concerning the experience curve: as more ethanol is produced, the production costs decrease due to learning effects. This will increase profits, inducing the industry to invest more and produce yet more ethanol. The reduced cost will also decrease prices with time (without decreasing profits) and that will have a positive influence on demand, pulling yet more production and closing another reinforcing loop (this and other feedback loops are omitted from this first diagram to avoid clutter but will be presented as each sector is detailed.).

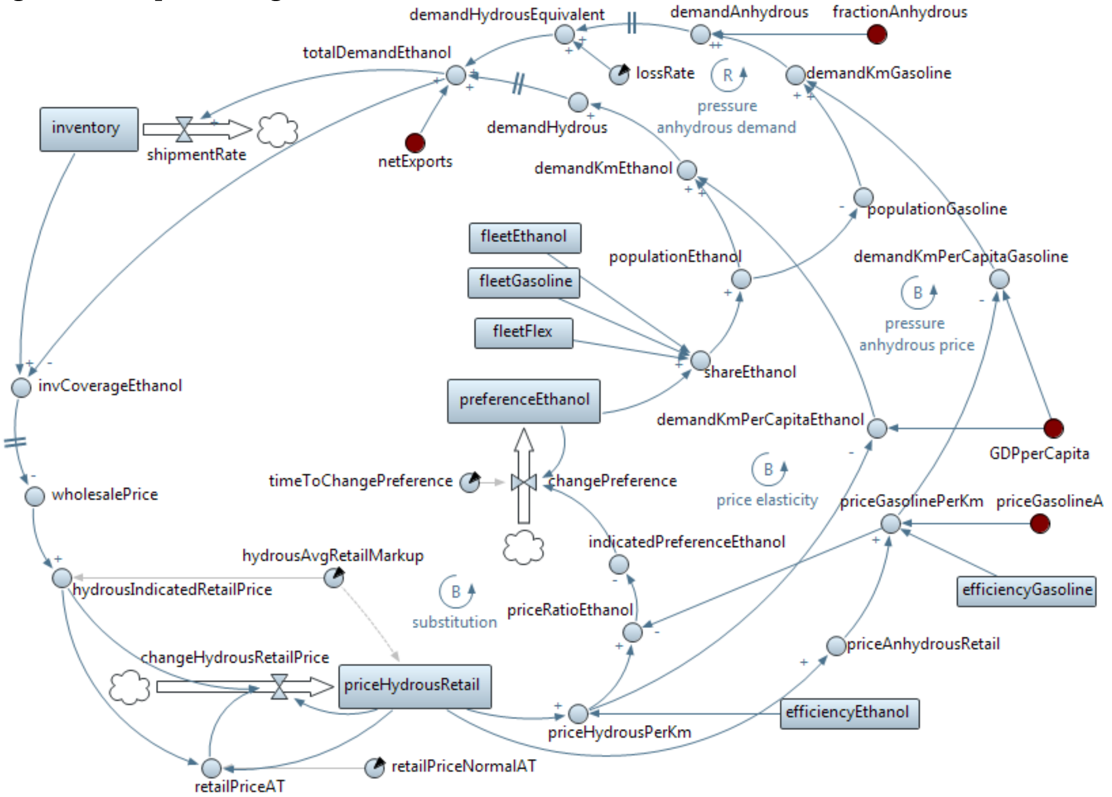
This first diagram also refers to the model boundaries with the shaded variables: price of gasoline, price of sugar, GDP and external demand. On a first iteration these variables will be exogenous to the model. Further iterations may include effects that make them at least partially endogenous, such as lowered production increasing the global price of sugar.

The following sub-sections present each sector of the model highlighting their main characteristics. The diagrams are all simplifications of the full model and are deliberately lacking parts so to avoid clutter and convey the main structure. The complete model is available in a separate document.

4.1. The demand sector

As discussed in section 2, demand for ethanol and gasoline are highly connected thanks to the flex-fuel vehicles. The demand for hydrous ethanol depends on what proportion of the population drives flex vehicles times the preference they have for ethanol instead of gasoline. This preference is a central variable in the demand sector (see Figure 16) and is modelled as a stock because there is inertia for changing it.

Figure 16. Simplified diagram for the demand sector



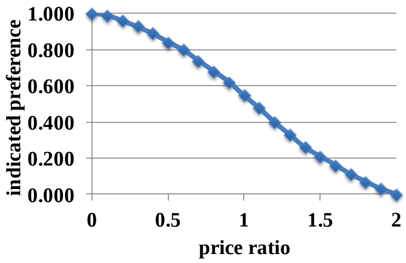
The demand for fuel is fundamentally driven by the income per capita and price. The demand is calculated from these variables according to the following equation: $D = K.Y^{\propto}.P^{\beta}$, where D is demand of Km per capita, Y is the income per capita and P is the price per Kilometre. The constant term K and the income and price elasticities (α and β respectively) were obtained statistically from historical data.

The model is concerned with demand for Kilometres instead of demand for fuel volume because the efficiency (e.g. in Km/litre) is different between ethanol and gasoline and because the efficiency changes over time as discussed in section 2. A similar approach is used by Ferreira et.al. (2009). The efficiency is modelled as a stock adjusting to an arbitrary maximum value with a fixed time constant (a rough simplification).

The total demand for each fuel is calculated based on the total population assigned to it. This assignment is based on the fleet size and on preference for ethanol. The fleet is modelled separately (not shown in the diagram) but it is only used to measure the proportion of vehicles of each type. This model is not concerned with "consumption per vehicle" as this concept is dubious: an increase in income may lead one household, for instance, to acquire another car; in the new setup the household will likely consume more Kilometres for the same price but the consumption per vehicle will probably be lower. The size of the fleet will also be highly correlated with income, which would advise against using both variables in the model. Losekann (2010) also seems to find that the size of the fleet might not be a good parameter to estimate total demand for fuel.

The preference for ethanol is a stock that adjusts to an indicated value with a time constant. The time is necessary for consumers to perceive and assimilate the changes in price and to take action. The indicated value depends on the relative price per Km between ethanol and gasoline and is defined by the non-linear relationship shown in Figure 17. Notice that there is a small bias towards ethanol: a ratio of 1 yields 55% preference for it[10].

Figure 17. Relationship between the price ratio (ethanol/gasoline) and preference for ethanol



Once the total demand in Kilometers is calculated for each type of fuel, the total demand in volume is calculated based on the efficiency again (not shown in the diagram to avoid clutter). The demand for gasoline drives the demand for anhydrous ethanol depending on the fraction to be mixed. This fraction is defined by the government and exogenous to the model. This will be one of the variables to be controlled when defining policies. The demand for anhydrous ethanol is converted to "hydrous equivalent" by adding the loss rate (the dehydration process removes ca. 4% in volume). Total demand for ethanol is the sum of hydrous and anhydrous (hydrous equivalent) demand, plus total net exports, which are also exogenous and will be defined in different possible scenarios.

The demand will have a negative effect on inventory coverage. It will drain the inventory of finished products while also decreasing the coverage directly. If there is a shortage, that is, demand grows bigger than production, inventory coverage starts to decrease and the price grows. A change in the wholesale price drives a change in the same direction in the retail price after some time. The time depends on whether the price is increasing or decreasing. If it is increasing (indicated price is bigger than current price) the time is smaller, that is, the price adjusts faster. A decrease in price will take longer to propagate as retailers wait until someone decreases the price and all others follow (Santos, 2012)[11].

A bigger price will have two effects: first the demand for "Kilometers of ethanol" will decrease according to the price elasticity; second, flex-fuel vehicle owners will start shifting to gasoline. These effects will both decrease the demand for ethanol, forming the two balancing feedback loops shown in Figure 16 ("price elasticity" and "substitution", respectively). Apart from these effects, the higher price will also pressure the price of gasoline as it contains anhydrous ethanol. This effect will also decrease

[10] The assumption is that the consumer will favour ethanol when prices are the same or very close. This hypothesis was apparently verified during model calibration.
[11] This non-linear effect on the time constant is called ratchet effect (Sterman, 2000).

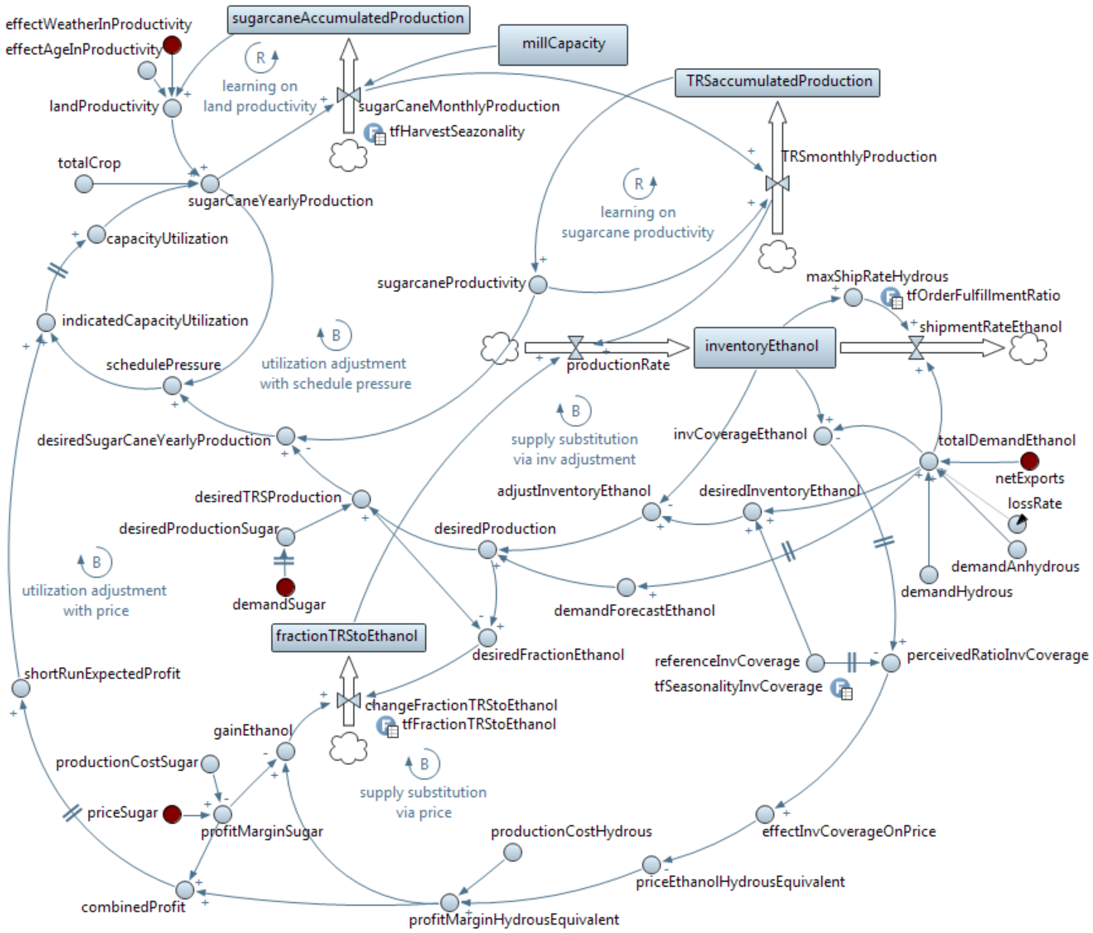
gasoline and ethanol consumption, though with a lower strength as the proportion of ethanol in gasoline is small. These effects will of course work on the other direction as well: a lower demand will increase coverage, reduce prices and shift preference back to ethanol and that will balance the demand again.

There is also a reinforcing feedback loop originated from the fact that gasoline consumes anhydrous ethanol as an additive. As the substitution takes place, demand for gasoline starts increasing and so does demand for anhydrous ethanol, which increases total demand for ethanol. This will put more pressure on the inventory coverage and a further increase in the price of hydrous ethanol.

4.2. Production Sector

Production starts with the sugarcane harvest. The variable 'sugarcane yearly production' (see Figure 18) defines the total production for one year observed at present. It is calculated as the total crop available times the land productivity and times the capacity utilization, as the mills might not be willing to use all the available sugarcane if the market is not attractive. The actual production, defined by the variable 'sugarcane monthly production' is distributed throughout the year according to a seasonal factor, defined in the model by a non-linear function as seen in Figure 13. Monthly production is also limited by the total mill capacity.

Figure 18. Simplified diagram for the production sector



The land productivity depends on effects of the crops' age, on the weather and on the accumulated production which gradually increases productivity with learning effects. The model is given by the following equation:

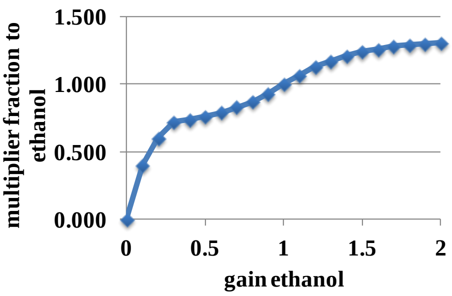
$lp = p_0 . CUM^b . effectAge . (1 - effectWeather),$

where lp is the land productivity, p_0 is the productivity for the first tonne produced, CUM is the accumulated sugarcane production and b is the experience index. The values for p_0 and b were found statistically based on historical data; 'b' is positive, as the productivity grows with the accumulated production. When modelling costs with the same experience curve concept, b will be negative as costs decrease with production (Bake et al, 2009). The effect of age in productivity will be defined in the crops sector. The effect of the weather is modelled as a normal distribution with arbitrary mean and standard deviation that changes once per year. For the model analysis and calibration it will be defined arbitrarily as zero or close to historical occurrences.

Sugarcane monthly production translates into TRS (total recoverable sugar) monthly production according to the sugarcane productivity. The sugarcane productivity is analogous to the land productivity and also grows with accumulated production, only the experience curve is different (or the parameters p_0 and b). As a simplification the model assumes that weather and crop age affect only the land productivity. Note that the diagram highlights two reinforcing feedback loops created by the effects of learning on land and sugarcane productivity. TRS monthly production defines the ethanol production rate according to a constant conversion factor and to the fraction of the TRS supply that is being assigned to ethanol instead of sugar (the production mix). This fraction assigned to ethanol is modelled as a stock, there is inertia to change it.

The fraction depends on the desired production of both sugar and ethanol and on the relative profit margin between them (called 'gain ethanol'). Producers will shift production to ethanol when its profit margin is bigger than that of sugar. There is a limit to how much production can be changed and the relationship is non-linear (see Figure 19). There is also a time associated to the change.

Figure 19. Relationship between ethanol's advantage over sugar and the fraction of capacity it gets



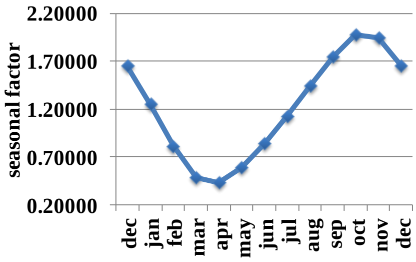
Limits to change the fraction exist because under the current setting it is impossible for the industry to change the production mix too much or too fast. Existing mills have dedicated equipment for one or the other product or are entirely dedicated to a single product. Apart from that there are synergies where by-products of one process feed the other, so it would be highly inefficient for the multi-purpose mills to start producing only sugar or only ethanol (Andrade, 2012). But in the long run these limits could change or disappear in extreme scenarios where demand for ethanol or for Brazilian sugar fade completely. The model assumes fixed limits for simplicity (the constants can be changed on a user interface) but a second iteration of development could better explore how these limits might change in the future.

Ethanol's production rate will feed the inventory of final products which will feed the demand. The inventory is given in total volume of hydrous ethanol in cubic meters. The production and inventory of anhydrous ethanol is aggregated together for simplification. The dehydration process is fast and so is the total production process. For that reason this model disregards work-in-process inventories and also the separate process to produce anhydrous ethanol.

The relationship between supply and demand is captured by the inventory coverage, defined as the total number of days of sales available in inventory at any given time. The coverage will have a big influence in the wholesale price. A higher than expected coverage means that prices will go down and vice-versa. But the price does not depend directly on the inventory coverage because it takes time for the market to measure it, so a second variable called 'perceived ratio inventory coverage' is added which accounts for the delay in perceiving the current value. The perceived ratio depends on a reference value which is not fixed: it depends on a fixed average value and on a seasonality distribution.

If production is seasonal, the reference value for the inventory coverage should also be seasonal, otherwise the price would face very big periodic oscillations. The market knows that production will be very low for some months, so it expects a proportionately lower coverage for the end of the period with low production (see Figure 20).

Figure 20. Seasonal distribution of expected inventory coverage



The reference value for inventory coverage will, apart from determining the price, also dictate the current desired level of inventory. If this desired value is different from the actual value, the gap will generate an adjustment to the inventory (positive or negative, depending on the sign of the gap) which will be added to the current desired production. Desired production also considers the future expected demand. The desired production, together with desired production of sugar, will drive the desired production for TRS and sugarcane, increasing or decreasing the schedule pressure which will, after an adjustment time, change the capacity utilization and the sugarcane production, closing the balancing feedback loop 'utilization adjustment with schedule pressure'. The inventory adjustment will also push for more fraction of TRS to be assigned to ethanol and close another balancing loop called ' supply substitution via inv adjustment'.

Price connects two other balancing feedback loops (see Figure 18). First, an increase in price will also increase profits, which will lead to a higher fraction of TRS to ethanol, increasing the production rate, the inventory and coverage. A higher coverage leads to a lower price, counteracting the initial dynamic. This loop is called 'supply substitution'. Second, a higher price and profit will increase the short run expected profit and mark-up, which will have a positive influence in the capacity utilization, thereby increasing production of sugarcane, TRS and ethanol. The higher production will increase the inventory and coverage bringing prices back down and closing the loop 'utilization adjustment with price'.

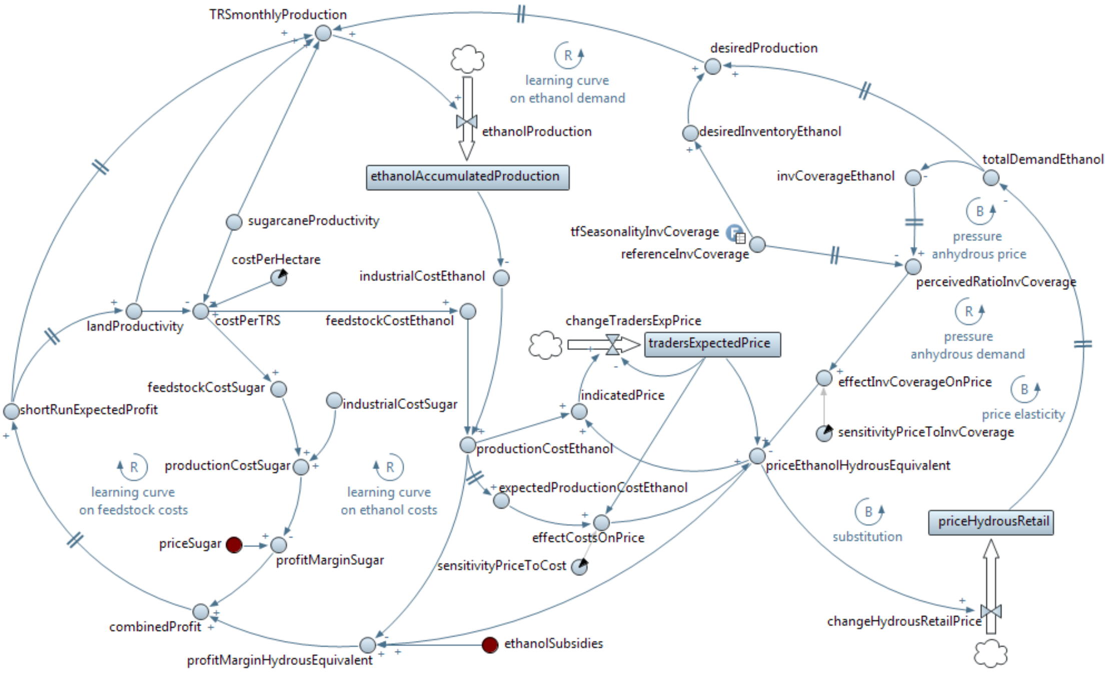
The total production of TRS and sugarcane depends on the demand for sugar which is an exogenous input to the model. The fraction of TRS to ethanol depends on the price of sugar which is also an exogenous input.

4.3.Price and Cost Sectors

The price of ethanol in the model depends on a memory of the recent price represented by the stock 'traders expected price' (see Figure 21).

This memory changes slowly, adjusting to the actual price. The adjustment depends on the variable 'indicated price' which is the maximum of the current price and the variable cost (a fraction of the total production cost), as the market will never expect a price lower than the variable cost. The actual price is the expected value changed by the effects of cost and inventory coverage. The inventory coverage dynamics were covered in the previous section. The diagram shows again the feedback loops associated with the demand and connected by the effect of the inventory coverage on price. The effect of costs on price also creates one important reinforcing feedback loop called 'learning curve on ethanol demand': production adds to the accumulated production which reduces the costs via learning effects; reduced costs will also reduce prices with time, which will have a positive influence in demand, increasing desired production and adding even more to the accumulated production.

Figure 21. Simplified diagram for the price and cost sector



The effects of inventory coverage and costs in price are given by the following equations:

$$effectInvCov = perceivedRatioInvCoverage^{sensitivityPriceToInvCov}$$

$$effectCosts = 1 + sensitivityPriceToCost.\left(\frac{expectedProductionCost}{tradersExpectedPrice} - 1\right)$$

$$price = tradersExpectedPrice * effectInvCov * effectCosts$$

The sensitivities are parameters to be adjusted during the calibration of the model. The sensitivity to inventory coverage is negative, meaning that the price will increase whenever the inventory coverage is below the reference value and vice-versa. The sensitivity to cost is positive meaning that the price will decrease whenever the total production costs are below the expected price and vice-versa.

The production cost has two components: the feedstock cost (all costs associated with producing the sugarcane) and industrial costs (associated with the mills' operations). Costs for sugar and ethanol are analogous and only change according to the conversion factors. The feedstock cost depends on a cost per TRS (total recoverable sugar) which depends on a cost per hectare divided by the land and sugarcane productivities. The cost per hectare is assumed constant on a first iteration of the model development but could be influenced by other factors, especially the cost of land which might have an increasing trend. A second iteration might consider a growing cost of land as the total crop approaches a physical limitation, but for now it will be exogenous and could vary on specific scenarios. The productivities grow with accumulated production which means that the cost per TRS has a downward trend.

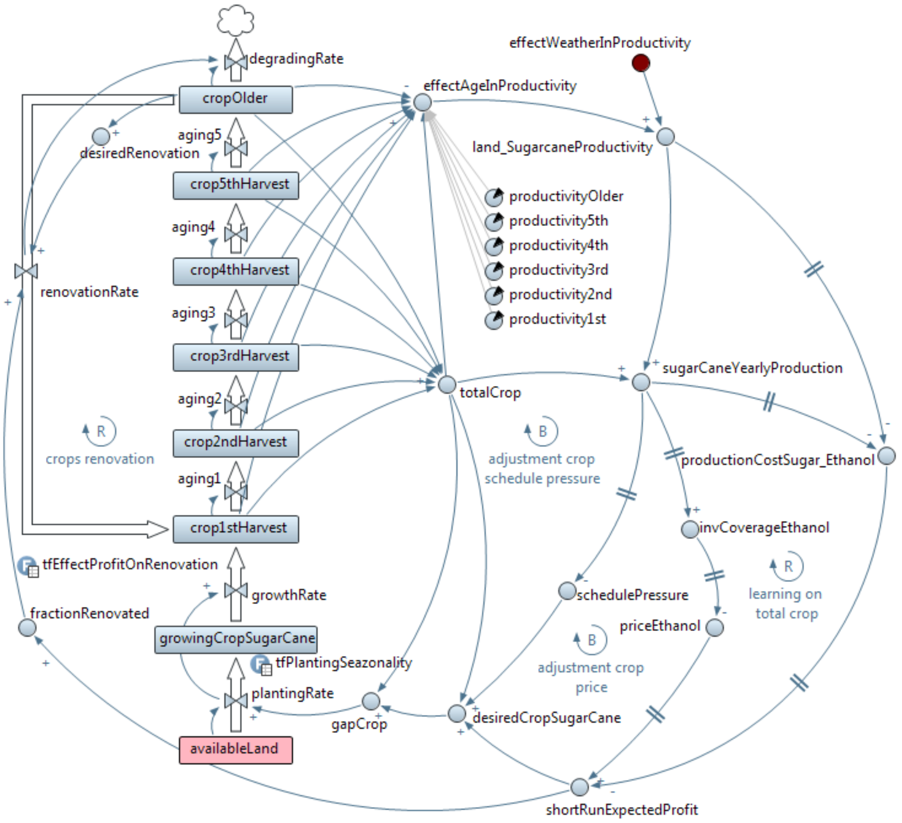
The industrial cost depends on the accumulated production according to the experience curve. Because sugar has been produced for a long time the model assumes (for simplification) that its industrial cost is fixed (only the feedstck cost will decrease with production). Bake et al (2009) found that the progress ratio for the industrial costs of ethanol was 81%. The model uses this value. The experience index is calculated as: $b = log_2(0.81) = -0.3040$ and $cost = c_0.CUM^b$, where c_0 is the cost for the first tonne or cubic meter produced and CUM is the accumulated production; c_0 was found by adjusting a value that would yield a cost in 2010 close to the ones informed by PECEGE (2011)[12]. Another exogenous effect called 'ethanol subsidies' was also included in the model to account for incentives (positive or negative) to the industry such as cost of capital or government subsidies. This variable stands for a factor which reduces or adds to ethanol's total production cost.

The industrial cost connects other reinforcing feedback loops. As production accumulates costs deacrease with the learning effects. Lower costs lead to higher profit margins which will have a positive influence in production after some time as shown in the production sector.

4.4. The crops sector

The sugarcane crop is modelled as an aging chain because the age of the crop is important in defining productivity as discussed in section two (see Figure 22).

Figure 22. Simplified diagram for the crops sector



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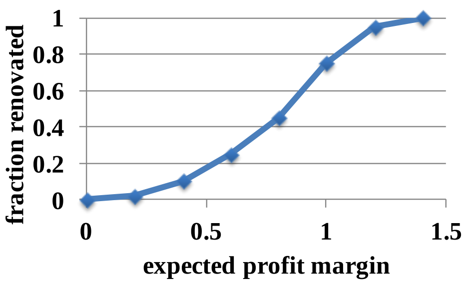
12 All parameter values and formulas are available in the complete documentation attached as a separate document.

There is a fixed amount of land available that can be turned into sugarcane crops. The total land available is exogenous and at first it is assumed not to represent a real constraint in the near future. The amount to be planted depends on a gap between the current size of the crop and the desired size. The desired crop depends on recent profits (producers will plant more if the profitability is positive) and on the scheduled pressure (for a given profit margin, producers will plant more if the demand increases). Planting is also seasonal and defined by a monthly factor.

Once sowed the sugarcane takes an average 15 months to grow (there are 12 months and 18 months varieties) after which it will enter the stock of crops in the first harvest. From then on the crop can be harvested once per year and so it will move to one crop older each year until it reaches the crops after the 5th harvest. On average the crops in Brazil are renovated one year after that, so the desired renovation is the total amount of older crops after one year. As a simplification the model assumes there is no renovation before the sixth year. A part of the crops that is not renovated will degrade with a time constant of 6 years and this area will be added back to available land.

Renovation will not always be equal to the desired value. The assumption is that renovation, like the planting amount, will depend on the recent profitability. High expected profits will induce producers to renovate all the old crops, but low profits will prevent renovation via a budget constraint. The relationship between expected profit and renovation rate is assumed non-linear and s-shaped (see Figure 23).

Figure 23. Effect of expected profit on the renovation rate



Productivity is lost for each year without renovation. The older the crops the lower the productivity (see Figure 8). As seen before, productivity is crucial in determining cost and consequently profits. That creates a reinforcing feedback loop: low profits will prevent renovation and increase the average age of the crops which, ceteris paribus, will reduce productivity, increase costs and reduce profits again in a vicious cycle. That actually seems to be happening now in Brazil and the government has devised a plan to rescue producers.

When the old crops are renovated, they return to the stock of crops in the first harvest. The sum of all the crops determines the total sugarcane yearly production and connects other feedback loops. The loop 'adjustment crop scheduled pressure' will control production via the size of the crops: overproduction will decrease schedule pressure which will also decrease the desired size of the crop. After some time this can reduce the total size of the crop and reduce production, balancing the initial dynamic. The loop 'adjustment crop price' also controls production via the price and size of the crop: overproduction will decrease the prices and the profit margin which will decrease the desired size of the crop. After some time this will decrease the total crop and balance production and the price again.

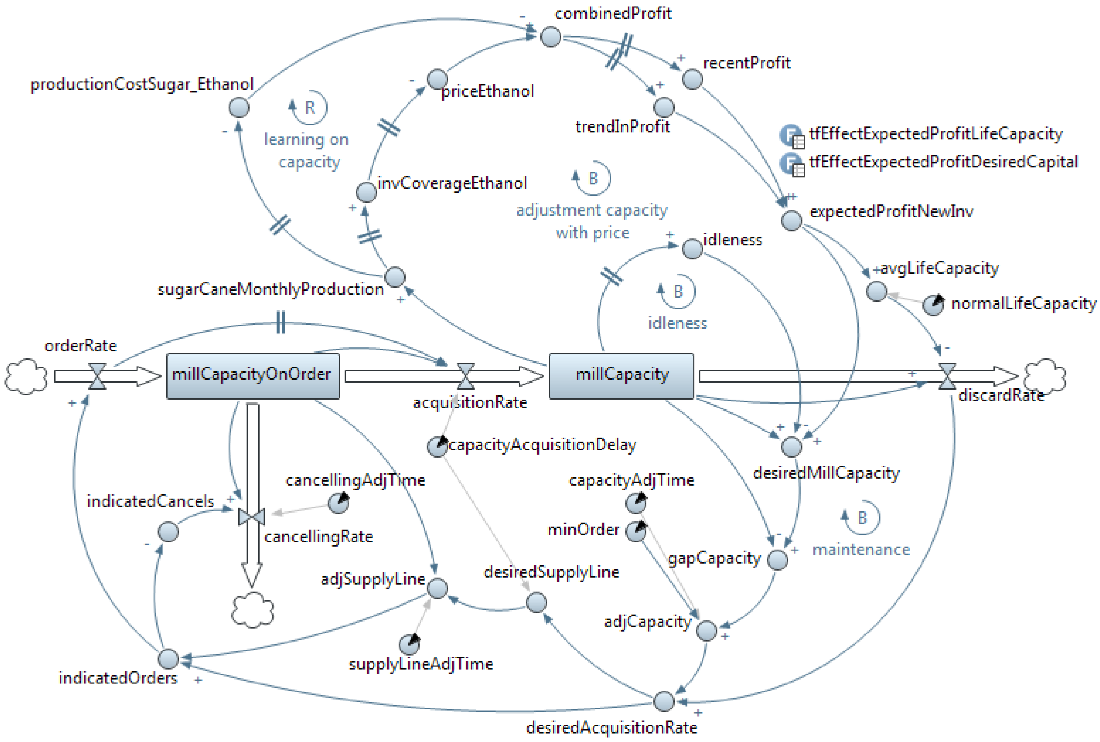
But there is also a reinforcing feedback loop related to learning effects. Production will lower costs in the long run, increasing expected profits and the desired crop size. A bigger crop will yield even more production, closing the loop. The reverse effects are of course also possible for all the feedback loops. It is worth noting that, although important, these loops are much slower than the loops in the demand and production sectors, as the sugarcane will take about one year and a half to grow.

4.5. Mills capacity sector

The last sector to be presented is the mills capacity. This is where the slower feedback loops are located and the long term dynamics are important (see Figure 24).

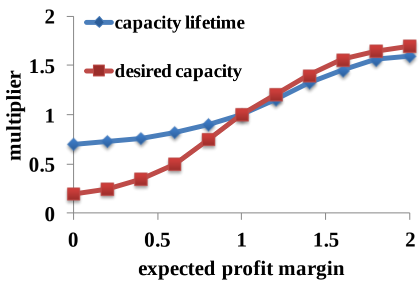
Capacity is given in tonnes of sugarcane per month, that is, how much sugarcane can be crushed per month. The stock of capacity is fed by the acquisition rate and exhausted by the discard rate. The discard rate depends on the average life capacity which is not fixed. If the expected profitability in the long run is positive, the life is extended, that is, the plants and equipments are used for a longer time.

Figure 24. Simplified diagram for the mills capacity sector



The future expected profitability also determines the desired capacity. A big future expected profit will prompt investors to build up more capacity. The relationship of both desired capacity and capacity lifetime is given by a non-linear relationship as shown in Figure 25. The multiplier for lifetime is applied to a normal life capacity of 30 years and for the desired capacity is applied to the current level of capacity.

Figure 25. Influence of expected profit in desired capacity and capacity lifetime



Desired capacity also depends on the idleness. If the profitability is high but there is still a high level of idleness in the industry (bigger than a "normal" value), then the desired capacity will not grow. That creates the balancing feedback loop called 'idleness'.

If the desired capacity is different from the current level, the gap will create an adjustment (positive or negative). The desired acquisition rate is the sum of this adjustment and the discard rate, as the mills must invest in maintaining the current capacity. The maintenance creates a balancing feedback loop: the more discards, the higher the acquisition rate so the capacity is kept in equilibrium.

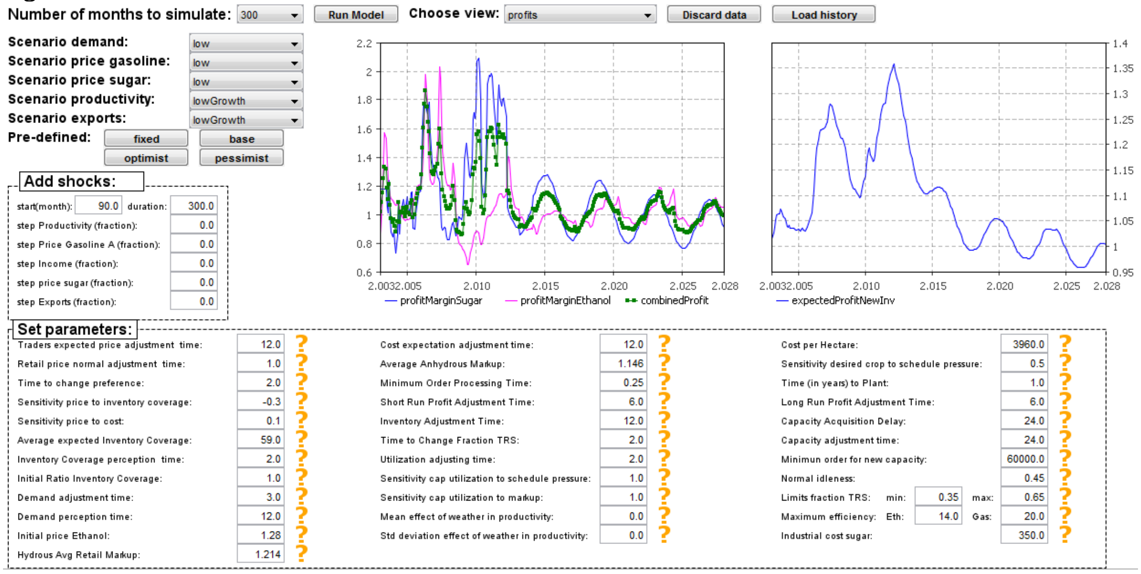
The desired acquisition rate will turn into orders unless it is negative, in which case it will turn into cancellations of capacity on order in case there is any. The inventory of capacity on order represents all the mills that are being built now. It is fed by the order rate and exhausted by the acquisition rate (mills that are finished and delivered) and by cancellations.

The capacity enables sugarcane production and connects other feedback loops highlighted in the diagram. In case there is too much capacity, inventory coverage will grow and prices will fall, reducing expected profits and the desired capacity. This configures the balancing feedback loop 'adjustment capacity with price'. But there is also a reinforcing loop called 'learning on capacity'. As capacity grows, so grows production. More production will reduce costs in the long run, increasing profits which increase the desired capacity and capacity lifetime. More capacity will translate into yet more production, forming a virtuous cycle.

5. Model analysis and validation

This section will explore the model's behaviour in order to validate the structure. A simulation interface was built to aid in the simulations (see Figure 26)[13].

Figure 26. Simulation interface



5.1.Behaviour reproduction test

The first test of behaviour attempts to reproduce the real development of the variables starting in January 2003. A base scenario was created in the simulation interface to set the historical data as an input for the exogenous variables.

Section 2 of this report presented several of the important variables through time. Even though we have many of the historical data on an yearly basis, that is not always the case for monthly data. As discussed, the model is concerned with monthly data because the seasonality can be highly relevant in defining oscillations in price.

Apart from periodicity, there are also other issues with the data available. Prices to producers are available for selected states only, not for the whole country, so the simulation uses the price in the Sao Paulo state (representing more than 60% of production) as a proxy. Prices of gasoline to consumers are different between all states and this test is using a weighted average (ANP, 2012). Prices of sugar are different between several varieties and the simulation is using just the most common variety as a proxy (CEPEA, 2012). Productivity and effects of climate are rough estimates.

The exact values of all the exogenous inputs in the base scenario can be found in the attached detailed documentation; a summary follows: Figure 27 shows the exogenous price of sugar and gasoline and Figure 28 shows GDP per capita and the fleet in the base scenario. The charts cover 10 years, until the end of 2012. All the prices have been converted to their value in December 2010 with the price index IGP-DI. The fraction of anhydrous ethanol in gasoline is kept at 25% throughout most of the period with brief reductions to 20% in some months during 2006, 2010 and 2011 (Zechin, 2012). Demand for sugar grows with the pattern shown in Figure 12 (section 2). The productivity is assumed to drop with weather effects as shown in Figure 34. Subsidies to ethanol are assumed to remain at 20% (a fraction of total costs) until the beginning of

[13] The simulation interface is available at http://www.runthemodel.com/models/k-FjOmbrk7ToJDkyGnJPVf/ (retrieved in June, 2012) so the reader can try it (it has been tested in Google Chrome,V19 and Firefox,V12)

2008, when the fleet of flex cars was soaring and there was general optimism with the market, and then remain at minus 20% from 2008 to 2011 when the global crisis increased the cost of capital and credit became scarce.

Figure 27. Exogenous prices in the base scenario

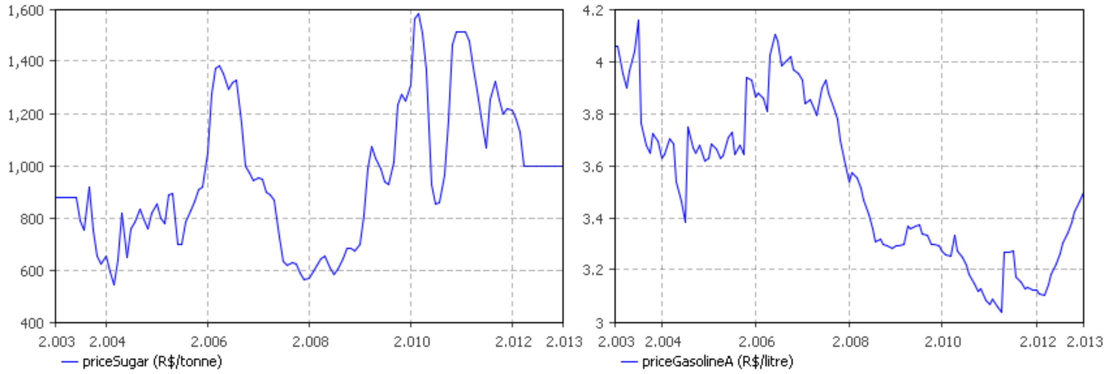
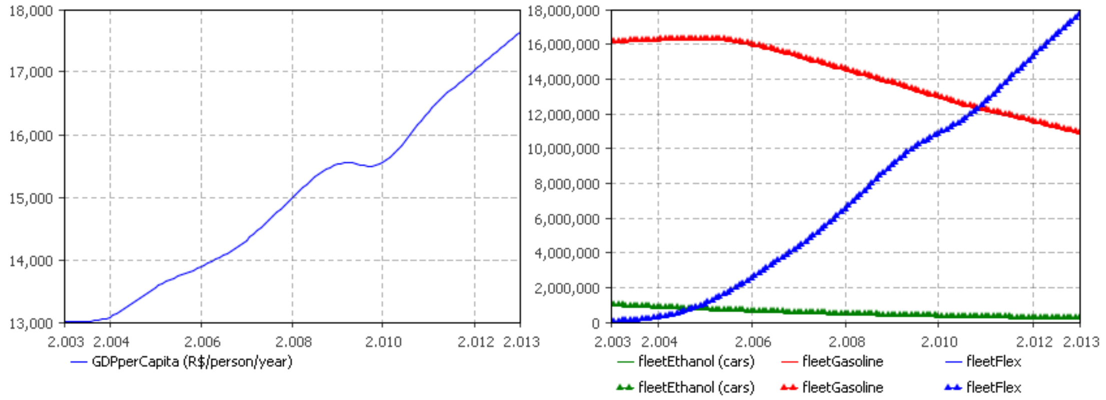
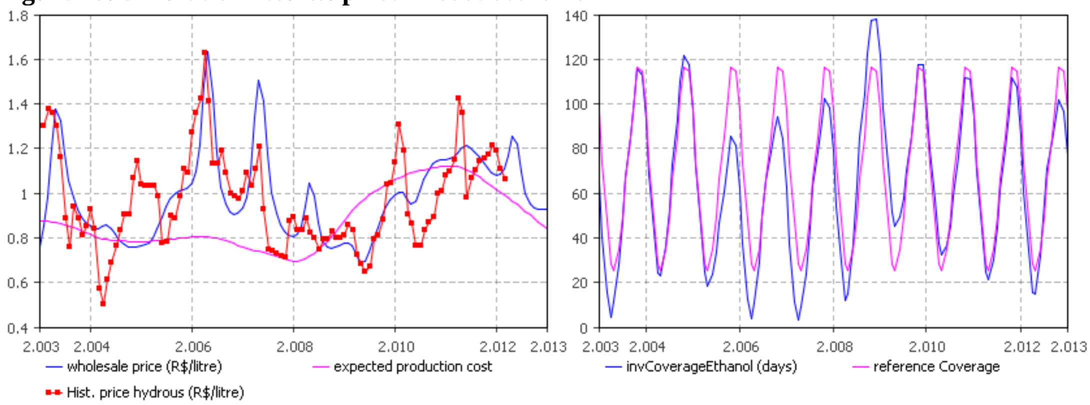


Figure 28. GDP per capita and fleet in the base scenario



This set of exogenous inputs yields the price curve displayed in Figure 29. The interface displays the resulting price and the historical data together on the same chart for comparison. The price data is obtained from CEPEA (2012) and refers to the price to producers in the state of Sao Paulo.

Figure 29. Simulation results: price in base scenario

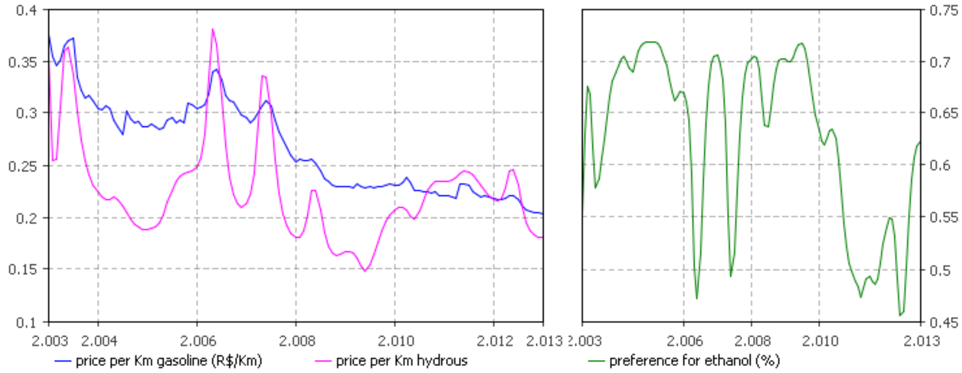


Even though the curves have a poor match (R^2=0.207) one can see the model responding with a similar pattern and with a small delay. Given the aforementioned issues with data and all the non-captured noise, one can conclude that the model's generated result is acceptable. Both the historical data and the simulation results show the price of ethanol responding to changes in the price of sugar and gasoline. At the beginning of 2006 and 2010, for instance, the price jumps after large rises in sugar price. In 2006 the growth is even bigger due to the high price of gasoline, which also pressures ethanol prices at the beginning of the simulation.

The prices of sugar and gasoline pressure the ethanol price via different mechanisms, the first acting on the supply side and the second on the demand side. With the changes on these inputs, the system tries to balance itself via the feedback loops discussed in section four.

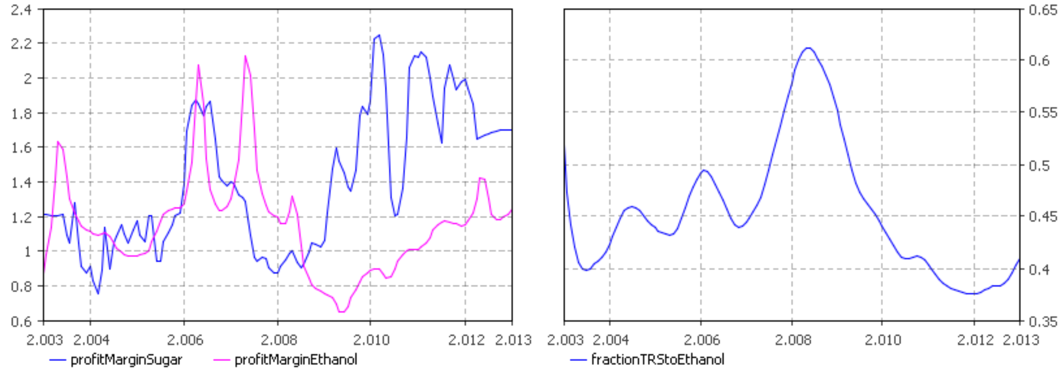
High prices of gasoline shift demand to ethanol and pressure the supply, decreasing inventory coverage and causing ethanol prices to also grow after some time. The increase in prices will eventually lower the demand, balancing the initial effects. The substitution effects can be seen in Figure 30.

Figure 30. Ethanol X gasoline in the base scenario



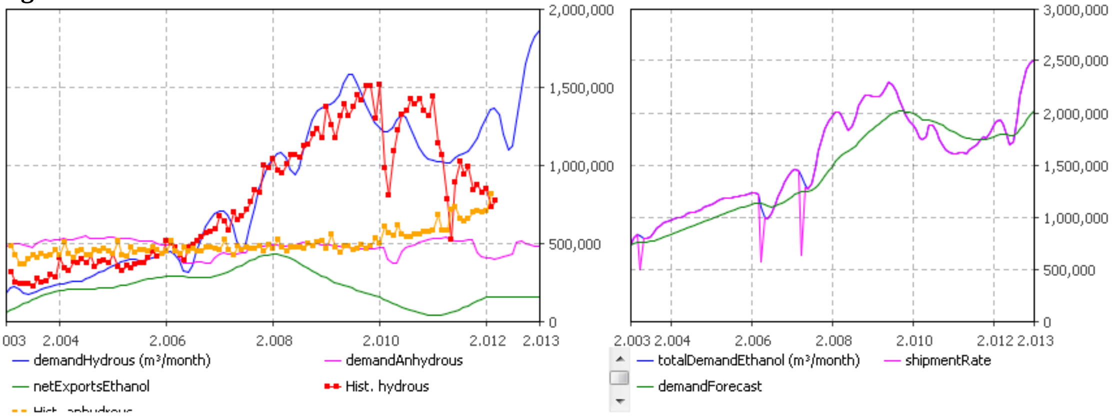
When sugar prices grow, they prompt producers to shift some of the raw materials and capacity to sugar (see Figure 31), which lowers ethanol supply and inventory coverage, thereby increasing prices. This growth will be balanced on the demand side afterwards with a decrease in demand.

Figure 31. Ethanol X sugar in the base scenario



The effect on demand can also be compared with available historical data (see Figure 32). Monthly fuel consumption is available from ANP (2012). The simulation results and historical data show a growing demand for hydrous ethanol which is the result partly of an increase in GDP per capita, but mostly of the major growth in the fleet of flex vehicles during this period. One can also see that as the fleet of flex vehicles grows, the demand becomes more volatile and highly dependent on the price of ethanol. Close to the year 2010, the increase in price causes a slash in demand as now the fleet of flex cars is close to 50% of the total and the shift in preference is fast after the changes in relative prices (see Figure 30).

Figure 32. Simulation results: demand in the base scenario



The effects on production can be seen in Figure 33. Production grows until 2009 and then starts falling as the price of sugar increases and the fraction of TRS to ethanol starts dropping (see Figure 31). Apart from that, effects of the weather also pressure production, both for sugar and ethanol, which impacts the price even further (see Figure 34).

Figure 33. Simulation results: production in the base scenario

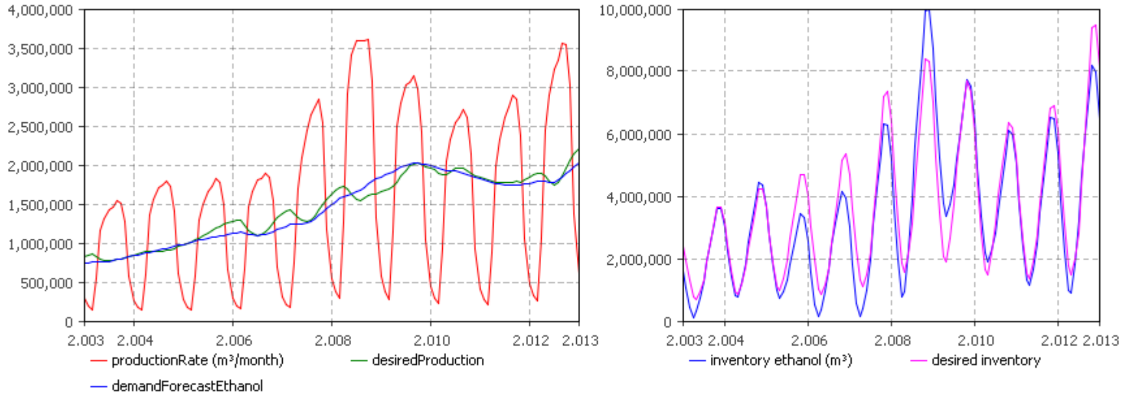
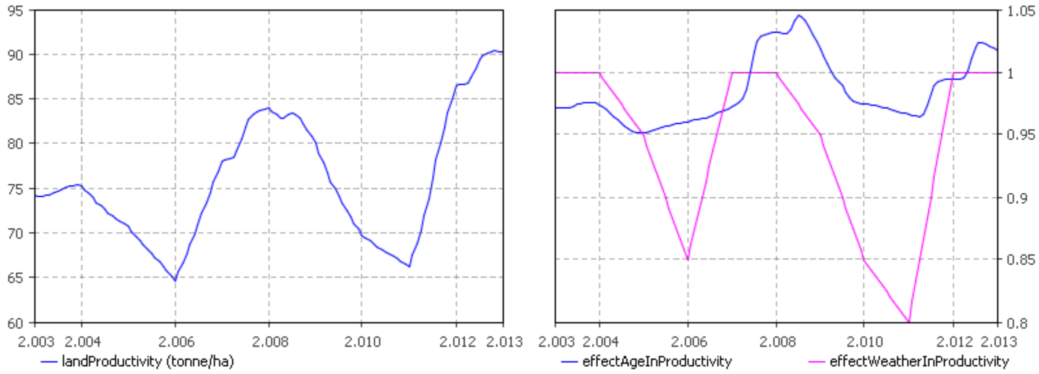


Figure 34. Productivity in the base scenario



On the supply side the long term effects are also acting to balance the system. Crops and mill capacity grow in response to the growing demand (Figure 35 and Figure 36) but they do so when expected profits are higher, which depends both on the sugar and ethanol markets.

The model's generated behaviour, though not precise, makes sense when compared to historical data. All variables vary on the expected direction with close magnitudes and small delays relative to the data. The following tests will explore the behaviour in relation to the structure more deeply.

Figure 35. Crops in the base scenario

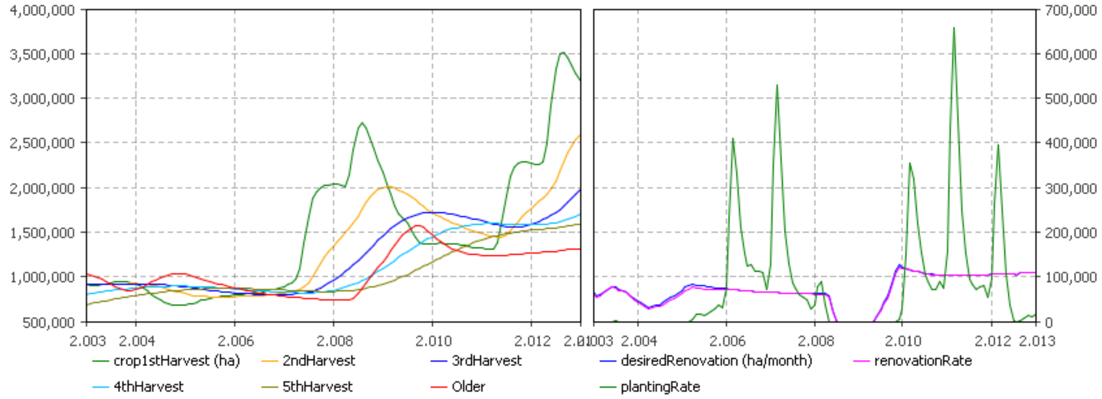
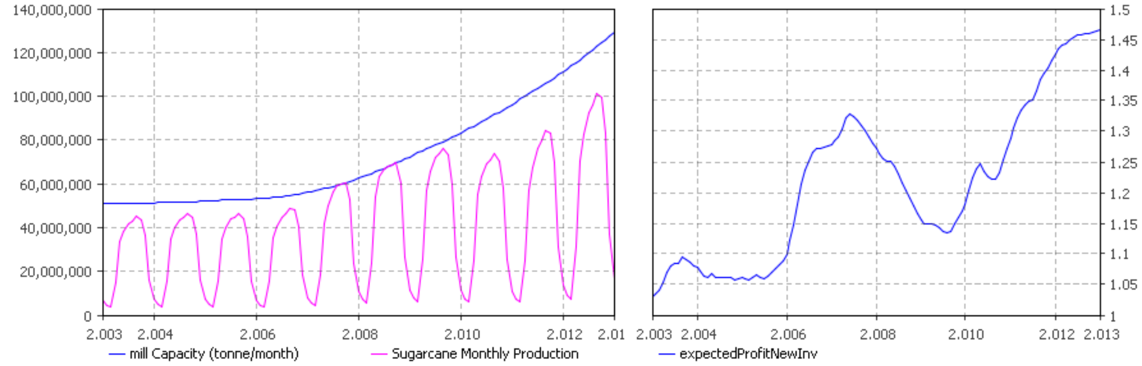


Figure 36. Mill capacity in the base scenario



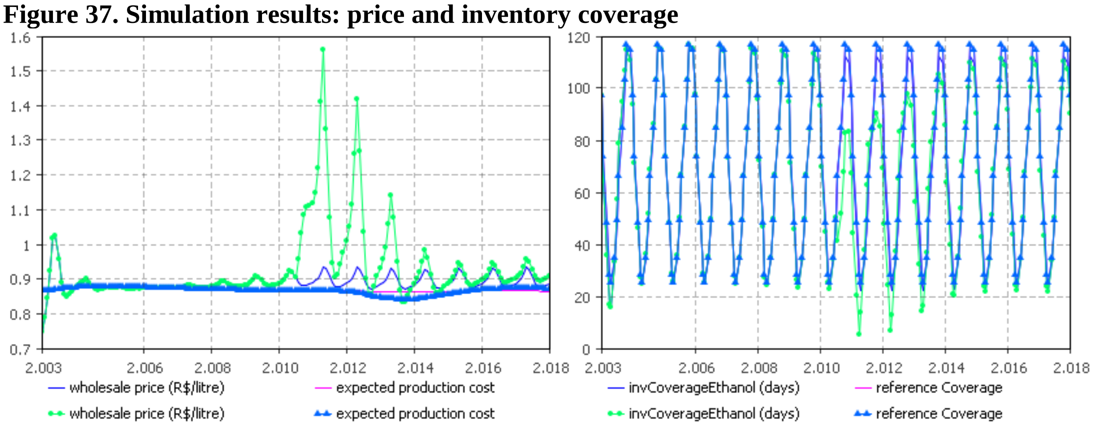
5.2. Other behaviour tests

Tests of behaviour were done on a hypothetical scenario of fixed demand for fuel (GDP and population are kept constant and so is the share of flex vehicles, at about 77%), fixed prices of gasoline and margin on sugar (price is kept 10% over costs), fixed productivity and exports. Vehicles' efficiency is also kept constant. Time horizon is 15 years for these tests and the system is shocked at year 7.5 (July of 2010).

5.2.1. Demand shock

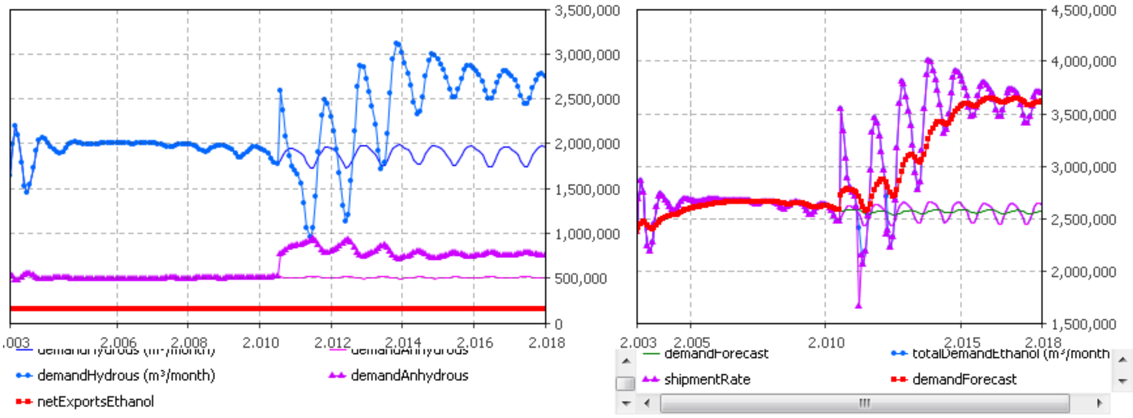
On the first test the system is shocked with a 50% increase in income. Figure 37 shows the results for the price and inventory coverage.

Figure 37. Simulation results: price and inventory coverage



The system starts off slightly unbalanced but soon reaches an equilibrium with small yearly oscillations in price due to the harvest seasonality. With the income shock the immediate effect is a sharp increase in demand (Figure 38), both for hydrous and anhydrous ethanol. But the increase in demand causes the inventory to deplete faster and the inventory coverage soon falls below the reference value which causes the price to jump. The increase in price then impacts the demand for hydrous ethanol, counteracting the initial effect.

Figure 38. Simulation results: demand



Part of the balancing effect is due to the price elasticity and part is due to the substitution effect (see Figure 41). As the price per km of hydrous ethanol grows faster than that of gasoline, preference for ethanol plummets and demand is balanced. The demand curves also show the demand for anhydrous ethanol growing as the demand for hydrous falls. This effect corresponds to the reinforcing loop 'pressure on anhydrous demand' and it lowers the strength of the balancing loops (see Figure 16 for a review of the feedback loops involved).

In order to test this effect one can apply a loop knock-out analysis (Sterman, 2000). By testing the same shock with a disconnected loop one can evaluate how important that loop was for the observed behaviour. Figure 39 shows the price for the same shock after the loops 'pressure anhydrous demand' and 'pressure anhydrous price' (see Figure 16) are disconnected. This is done simply by changing anhydrous demand to a constant value of 500,000 m³/month. Figure 40 shows the results for the demand.

Figure 39. Price with income shock and anhydrous loops disconnected

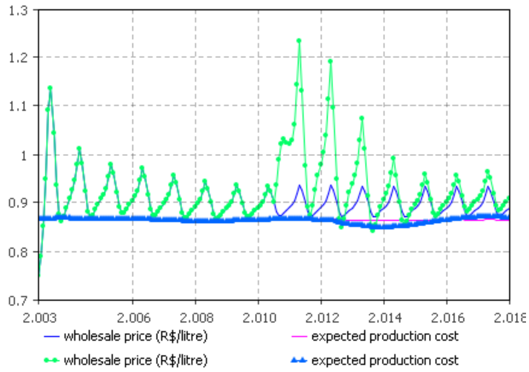
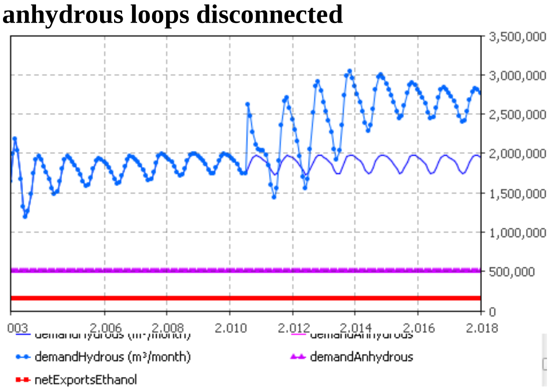


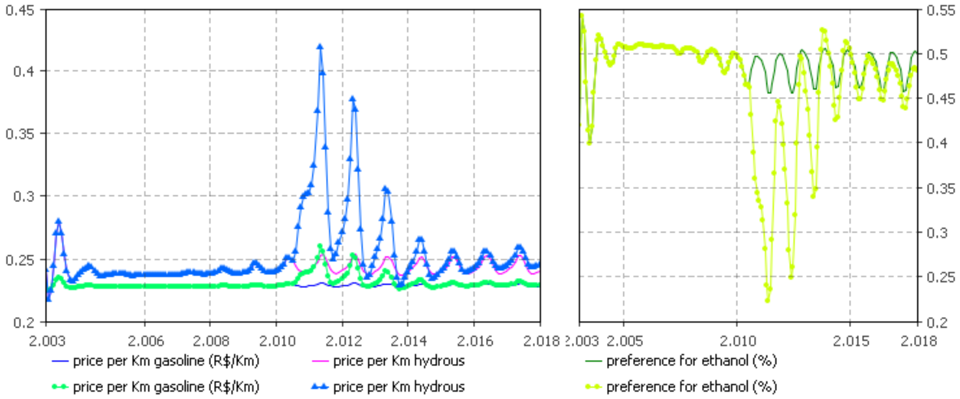
Figure 40. Demand with income shock and anhydrous loops disconnected



When comparing the results it is striking that the variations in price and demand are much bigger when the anhydrous loops are active, which attests the significance of the reinforcing loop 'pressure anhydrous demand'. This result also warns of the importance of the fraction of anhydrous ethanol in gasoline when defining policies.

Back to the original results, because the balancing effects involve delays, the system actually oscillates. As demand loses strength, inventory coverage rises fast again and soon it grows bigger than the reference value which causes the prices to fall sharply. The correction is bigger than needed because of the delays in the system. With prices falling, the demand (which is still pressured with the higher income) grows back again, pressures the prices again and the cycle repeats for about four years until the system stabilizes.

Figure 41. Simulation results: price per km and preference for ethanol



Apart from the balancing loops on the demand side, several other loops on the supply side are also acting in response to the shock (see Figure 18 for a review of the feedback loops involved). Figure 42 shows the production rate growing after the demand shock. Desired production grows with the higher demand forecast and on the first years after the shock it fluctuates around the forecast due to the necessary inventory adjustments. The delays to increase production cause the system to oscillate.

During the first years, increase in production is obtained partly with an increase in capacity utilization (Figure 43) and partly at the expense of sugar production: fraction of TRS to ethanol grows (Figure 44). These are the fast balancing feedback loops on the production side.

Figure 42. Simulation results: production and inventory

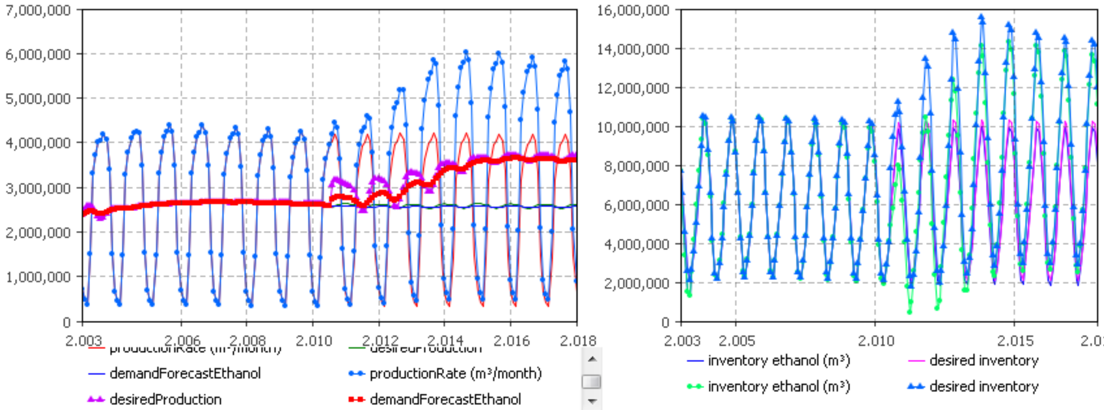


Figure 43. Simulation results: capacity utilization and total crop

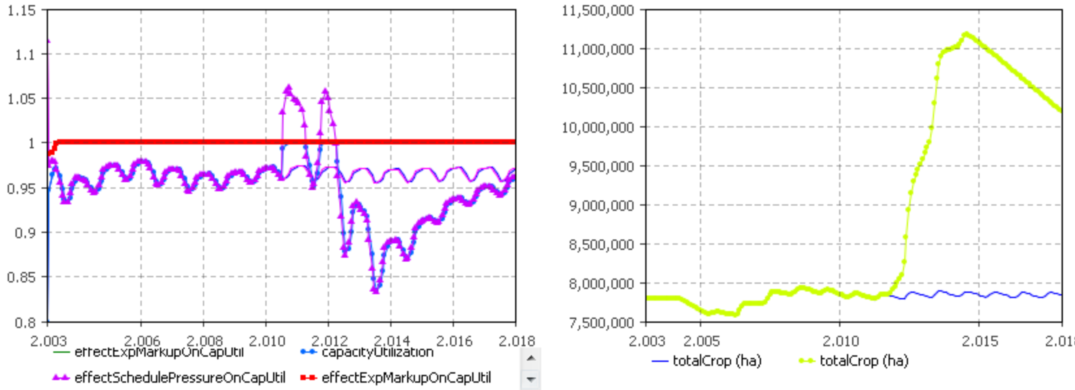
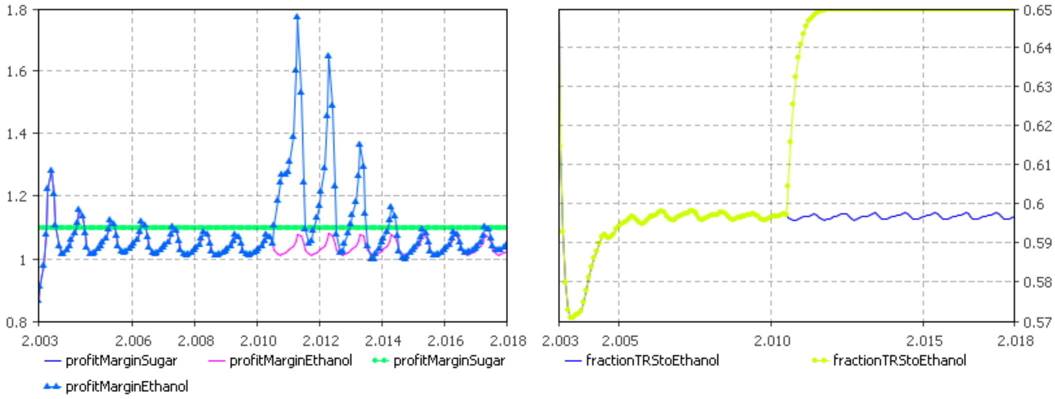


Figure 44. Simulation results: profit and sugar supply



After some time the slow negative feedback loops act to balance the system: the crop size grows (Figure 46) and so does capacity (Figure 47). The growth in crop size increases the proportion of young crops and that has a positive side effect on productivity with a betterment of the age effect (Figure 45).

Figure 45. Simulation results: productivity

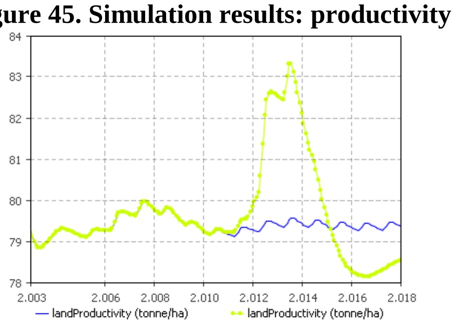


Figure 46. Simulation results: crops

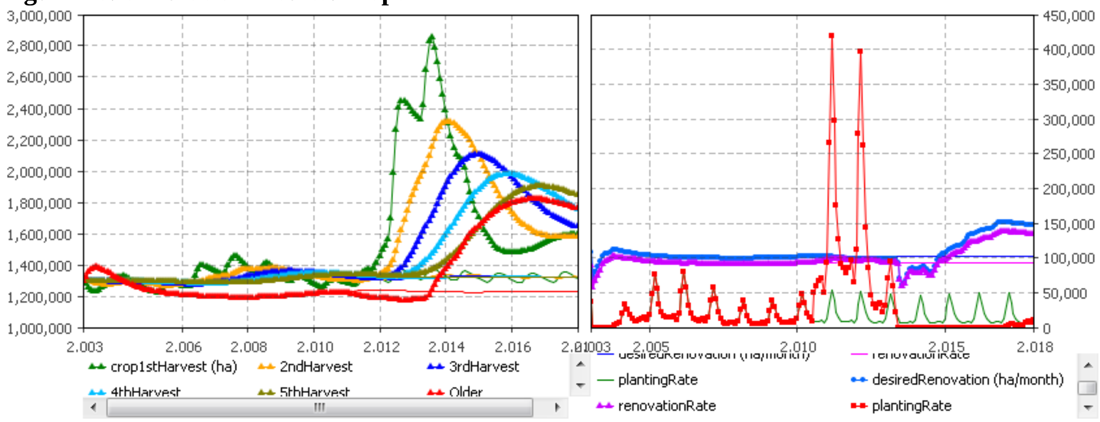
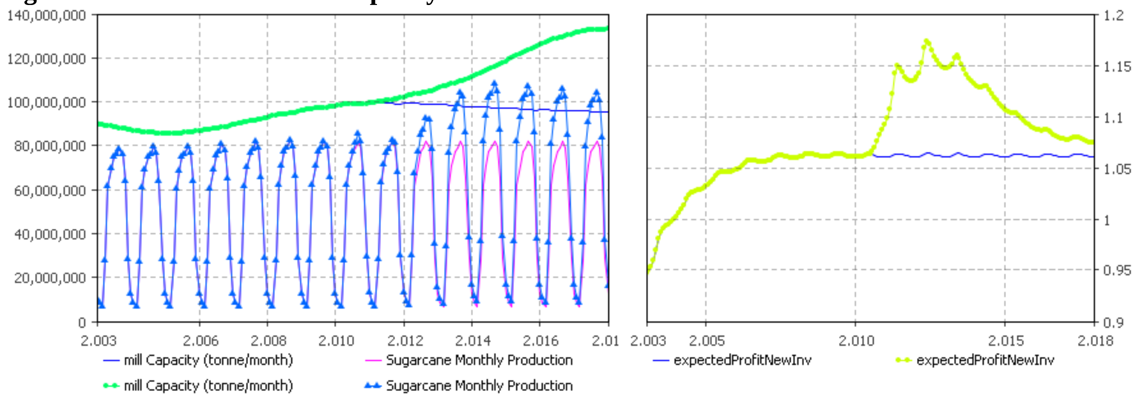


Figure 47. Simulation results: capacity



After about four years the price returns to its original level and stabilizes again with a small (negligible) oscillation. It does so because the cost remains constant and acts as an anchor to the price. The preference for ethanol, capacity utilization and productivity also return to their original values. But demand stabilizes at a higher level, compatible with the increased income and the supply adjusts with a higher capacity, larger crop area and a bigger fraction of TRS to ethanol.

5.2.2. Gasoline price shock

A similar effect happens when the system is disturbed with a shock that increases the price of gasoline in 50%, a hypothetical scenario of a major oil crisis.

Ethanol prices grow sharply after the shock and oscillate, also for about four years, before stabilizing at the same level (Figure 48). The price is being pressured by the growing demand as before, but now we see a sharp increase in hydrous ethanol demand at the expense of gasoline and anhydrous ethanol (see Figure 49). The shift in demand happens mostly by substitution as gasoline prices soar and most flex-vehicles' owners move to ethanol (Figure 50).

Figure 48. Simulation results: price after oil shock

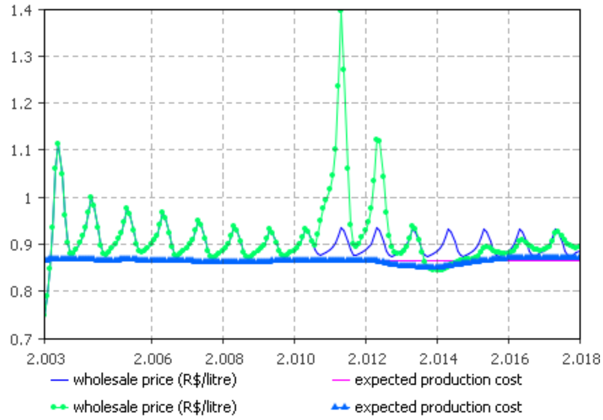


Figure 49. Simulation results: demand after oil shock

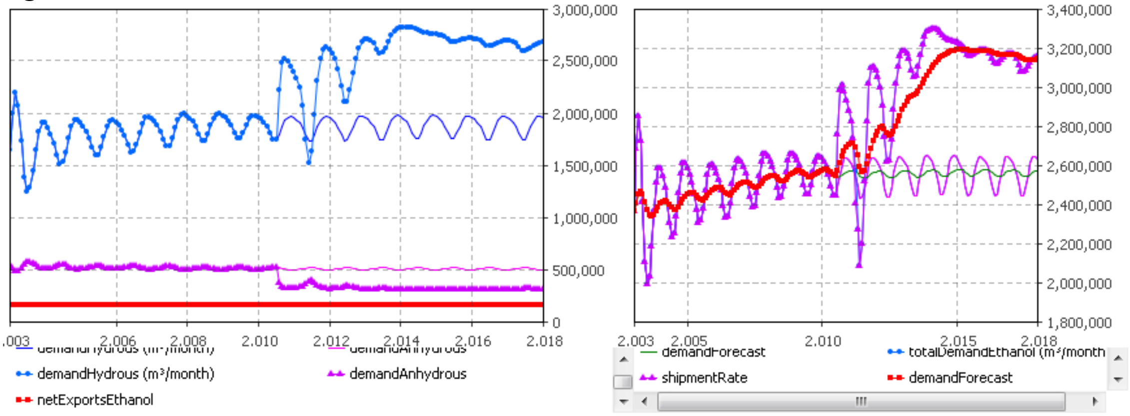
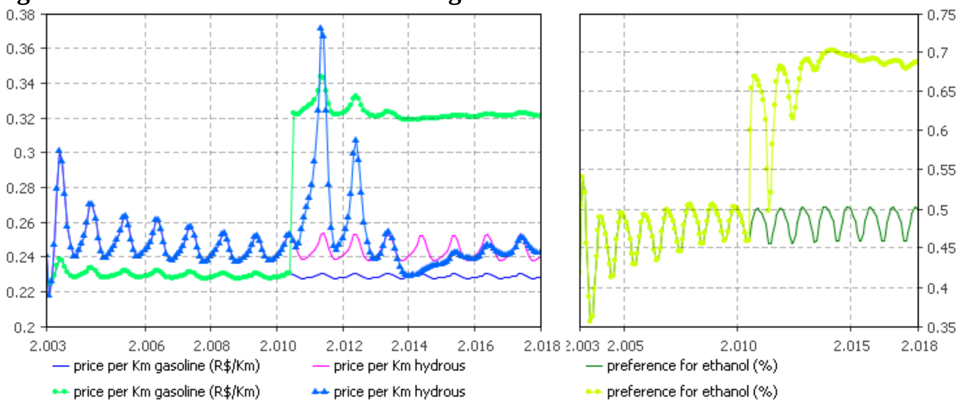


Figure 50. Simulation results: ethanol x gasoline after oil shock



But the delays also cause the system to oscillate. As demand jumps ahead of supply the low inventory coverage pressures the price. Price per km of hydrous ethanol grows sharply, going even above that of gasoline and bringing demand down again temporarily. The cycle repeats for a while before the system stabilizes again as with the previous shock. The effects in supply are similar with this shock, only with a greater magnitude. The final levels of the crops, mill capacity and fraction of TRS to ethanol all stabilize at higher levels.

A shock in the volume of net exports also has very similar effects as the increase in income. It also translates into an increased demand which pressures prices until the supply catches up and causes oscillations until the system stabilizes with more crops and capacity. We could also get opposite effects with negative shocks, for instance a drop in income (e.g. from a big economic crisis) or a drop in gasoline prices (e.g. in a scenario where Brazil starts exploring large volumes of oil and the global price drops). One can also get quite different results by shocking the supply side, for instance, with a shock in the productivity rates.

5.2.3. Productivity shock

As discussed in section 2, productivity has been growing considerably and is likely to keep growing, eventually with big jumps (for instance if research enables ethanol production from the bagasse). This perspective turns tests with shocks in productivity even more relevant. Figure 51 shows the results for price and inventory coverage after a shock where productivity grows 50% at July 2010. Figure 52 shows the results for production and inventory.

The first effect is a drop in costs and some overproduction due to the high productivity which cause the price to plummet. With the drop in price, demand responds fast and moves to a new, higher level that will be maintained despite the initial oscillations (Figure 53). And even though the system oscillates for some years after the shock, the price never goes back to the original level as now the cost has dropped almost 40% and it defines a new anchor for the price.

Figure 51. Simulation results: price and inventory coverage after productivity shock

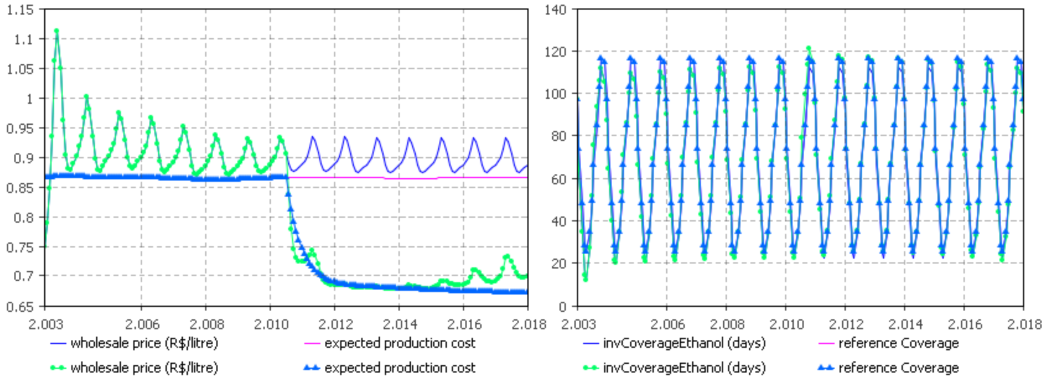


Figure 52. Simulation results: production after productivity shock

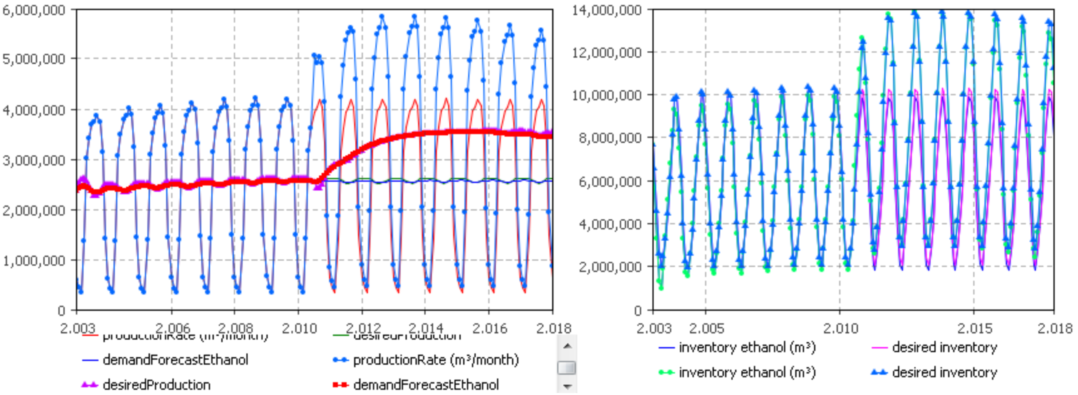
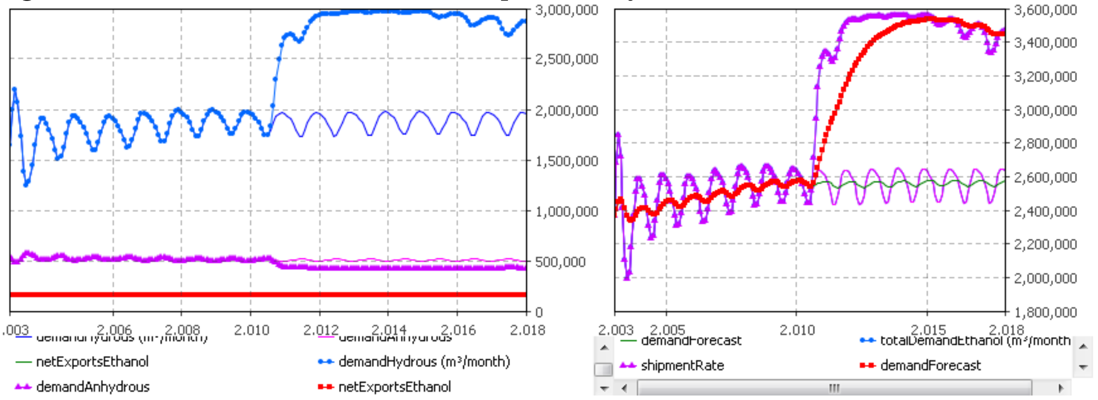
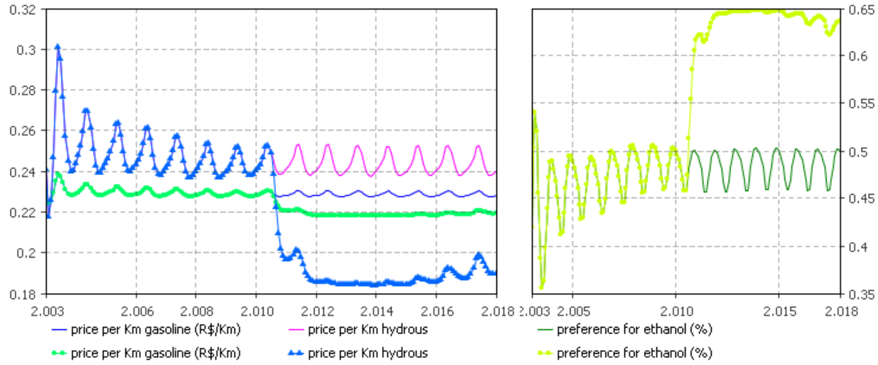


Figure 53. Simulation results: demand after productivity shock



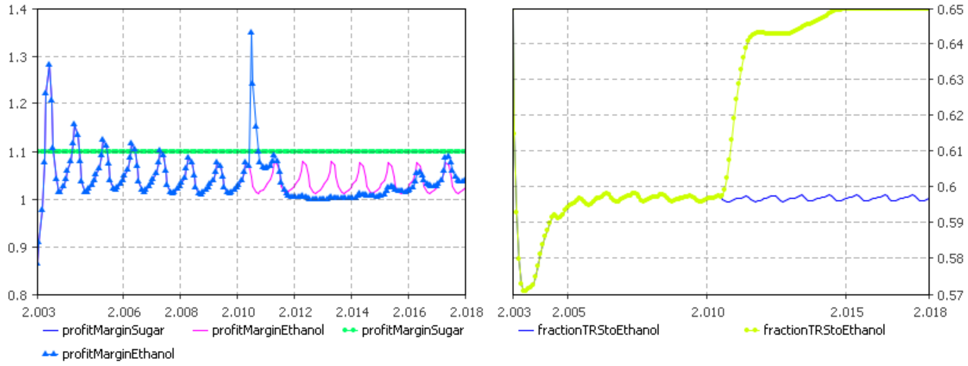
Demand for hydrous ethanol grows robustly both with the normal elasticity and as consumers shift from gasoline to ethanol (Figure 54).

Figure 54. Simulation results: ethanol x gasoline after productivity shock



In the new configuration about 65% of flex cars owners are using ethanol exclusively profiting from the lower cost. The profit for ethanol producers grows at the beginning but then oscillates and stays lower for a long time before returning to original levels. This result is surprising: consumers are benefiting more than producers from the gains in productivity[14]. But even so the fraction of production to ethanol stays high to attend the higher demand (Figure 55).

Figure 55. Simulation results: ethanol x sugar after productivity shock



On the supply side the balancing feedback loops are acting to stabilize the system after the shock. On the short run, capacity utilization drops to decrease production and on the long run the total crop area diminishes considerably now that the yield has grown so much (Figure 56). A side effect can also be seen on productivity: it falls after the shock because of the drop in the crop area (Figure 57). The planting rate falls and the average age of the crop stays high for some years, which causes productivity to fall during this

[14] If the productivity gain is achieved by one or a few producers only, they would benefit from a low cost and not so low prices.

period. Production is still bigger (pulled by the bigger demand) so the total mill capacity also grows.

Figure 56. Simulation results: utilization and total crop after productivity shock

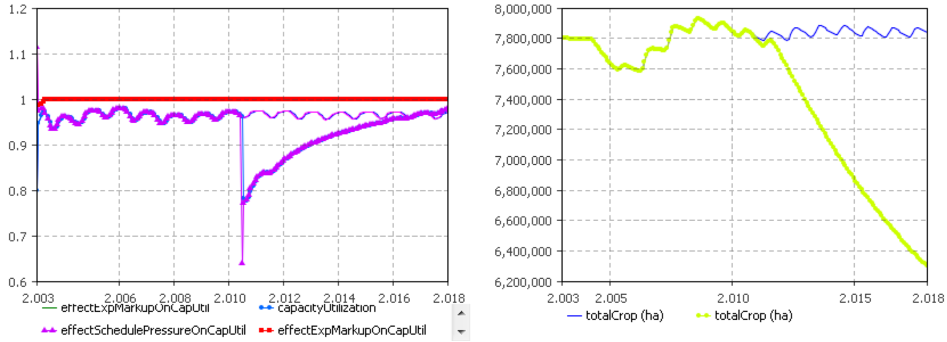
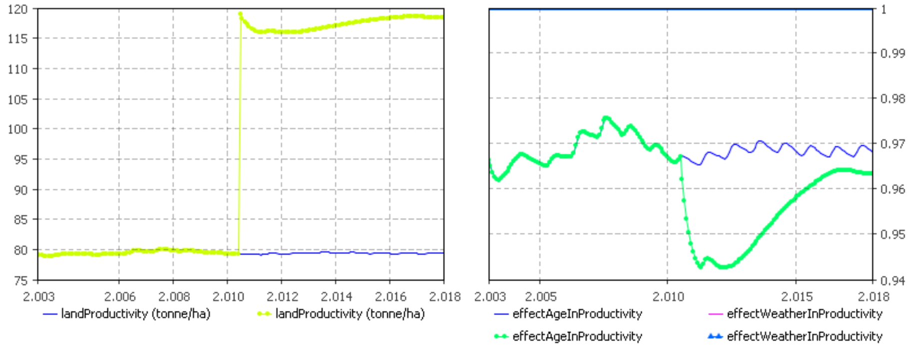


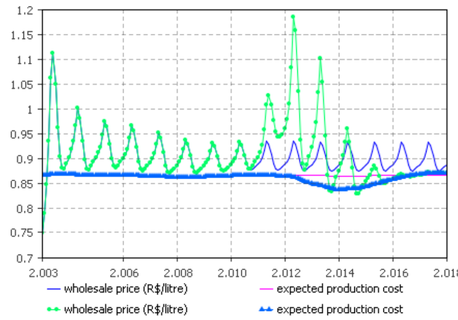
Figure 57. Simulation results: productivity after the shock



5.2.4. Sugar price shock

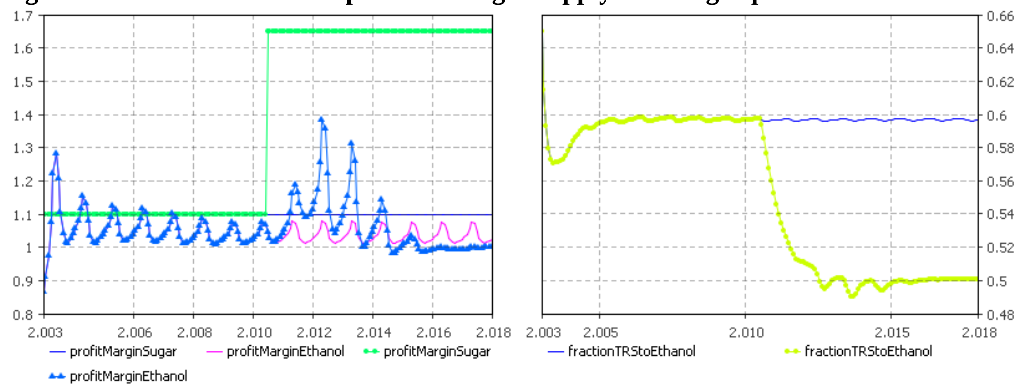
The supply side can also be shocked via the sugar price. The next simulation assumes an increase of 50% at the price of sugar at July 2010. This shock could be the result of, for instance, bad weather conditions in Asia damaging the sugarcane crops and reducing the global supply of sugar. Figure 58 shows the results for the price of ethanol after the shock. Price oscillates for about four years before stabilizing at a slightly lower level.

Figure 58. Simulation results: price after sugar price shock



The price of ethanol grows initially because of a lower supply. As sugar prices jump, so does the sugar expected profit which prompts producers to quickly shift production to sugar at the expense of ethanol (Figure 59).

Figure 59. Simulation results: profit and sugar supply after sugar price shock



Production of ethanol drops as a consequence (Figure 60) and oscillates for a while but later on it recovers to a higher level than before the shock. Demand also recovers after oscillating for some years (Figure 61). The recovery happens because even though sugar is now consuming a bigger fraction of capacity and raw materials, the size of the crops and capacity have grown more than enough, pulled by the high profits in the mean time.

Figure 60. Simulation results: production after sugar price shock

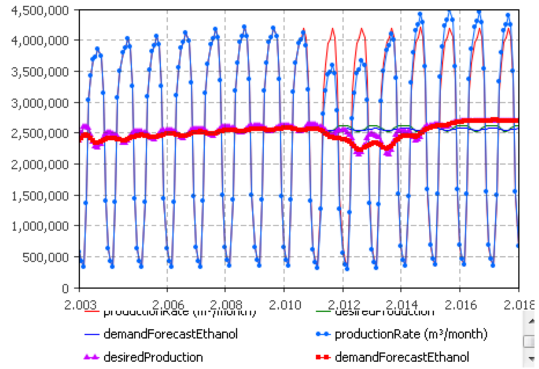
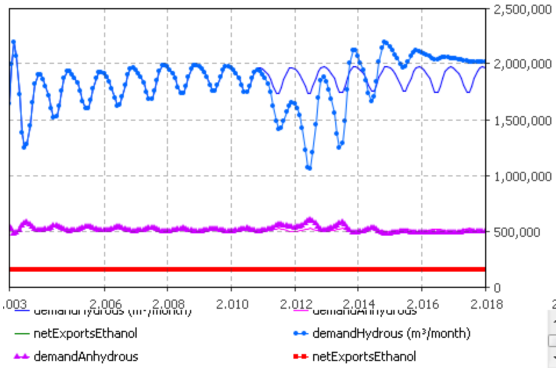


Figure 61. Simulation results: demand after sugar price shock



The opposite effect can be hazardous for the industry. The following simulation assumes a 30% decrease in the price of sugar, which could happen if global demand decreased or supply grew much faster. For this test the parameters that limit the production mix (called 'limits fraction TRS') were changed so the mix can go from 0 to 100% ethanol. Figure 62 shows a bigger cost and lower price for ethanol soon after the shock. The profitability of the ethanol market is hurt despite the fact that the price drop happened on the sugar market to start with. This result denotes how closely related the commodities are.

Figure 62. Simulation results: price after sugar price drop

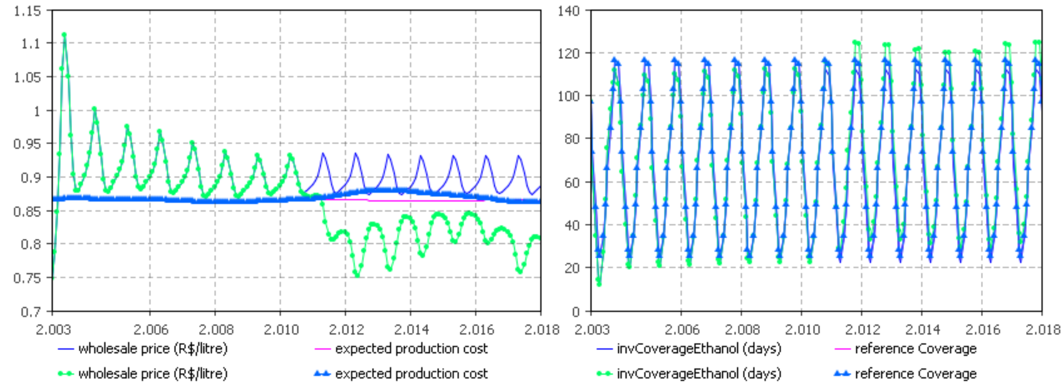
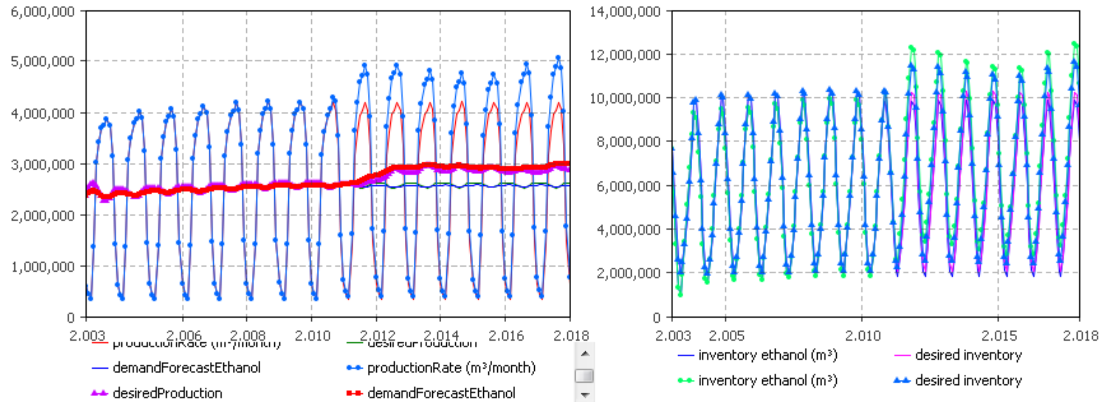
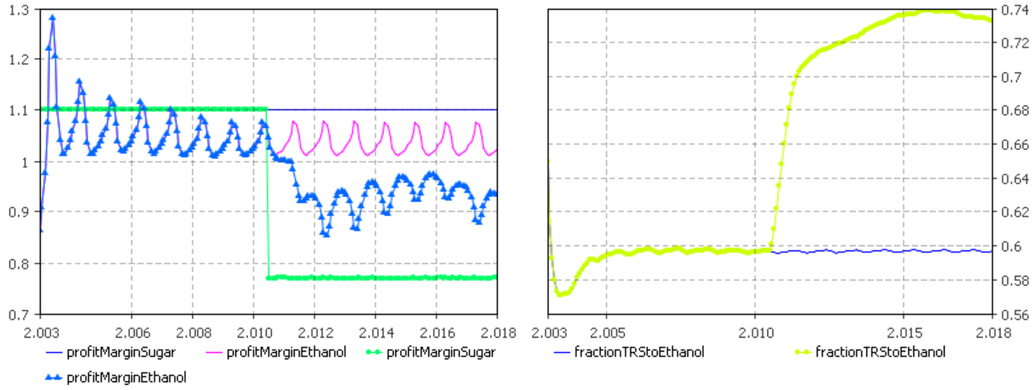


Figure 63. Simulation results: production after sugar price drop



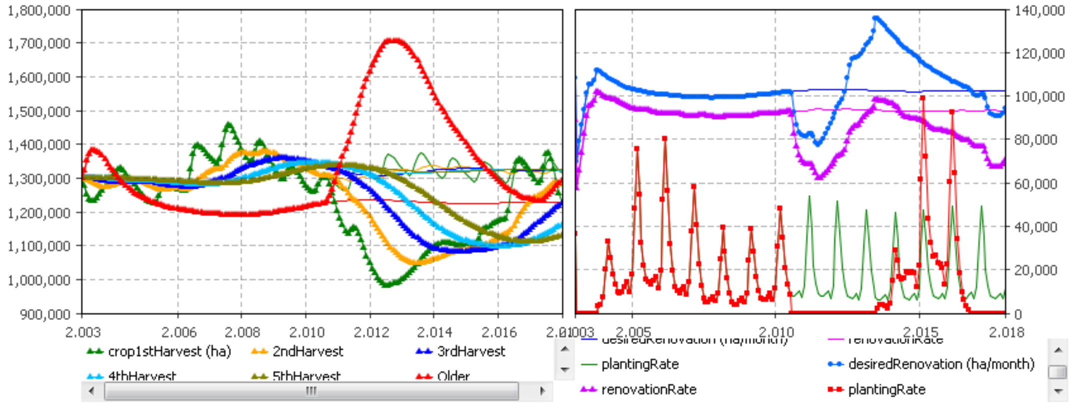
The lower price is a result of overproduction (Figure 63). With the low price for sugar profits plummet and the industry quickly shifts a big part of the production to ethanol instead of sugar (Figure 64), which floods the market with more ethanol, increasing the inventory coverage way above the reference value and bringing the prices down. After some oscillation, the prices stabilize in a lower level, below the costs, hurting the industry profitability.

Figure 64. Simulation results: profit and fraction of TRS after sugar price drop



Another harmful side effect can be seen on productivity. As the profit drops, so does the industry's desired crop area and capacity. Planting stops and the crops start getting older (Figure 65). The aging decreases productivity (Figure 66) which pressures the costs and contributes to decrease the profitability.

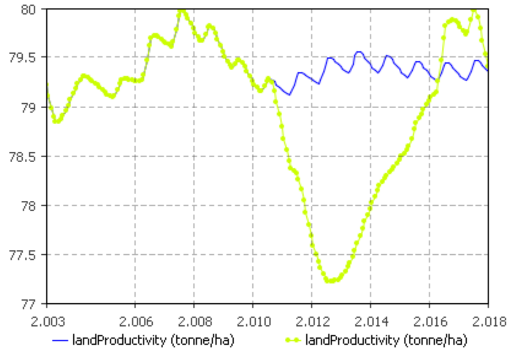
Figure 65. Simulation results: crops after sugar price drop



The effect is aggravated by the lower renovation rate (due to the lower profits) which keeps the crops old for longer. The simulation shows the reinforcing feedback loop 'crops renovation' (see Figure 22) hurting the industry by keeping profits low.

This result would be less severe if the limit to the production mix was kept at 65%. In that case ethanol production would not grow as much and the drop in prices would be smaller.

Figure 66. Simulation results: productivity after sugar price drop



One can also test the same shocks in different scenarios. For the next test the productivity is set to "base" scenario: it will grow with accumulated production and be affected by the weather as in the base scenario. The same shock with the 30% drop in sugar price is less traumatic in these case as now the growing productivity tends to decrease the costs. Figure 67 shows the results for the price and cost. Now the cost has a downward trend with the growing productivity and the price follows. Figure 68 shows how the profit margin of ethanol gets closer to break even at the end of the simulation if compared to the previous run.

Figure 67. Simulation results: price after sugar price drop with growing productivity

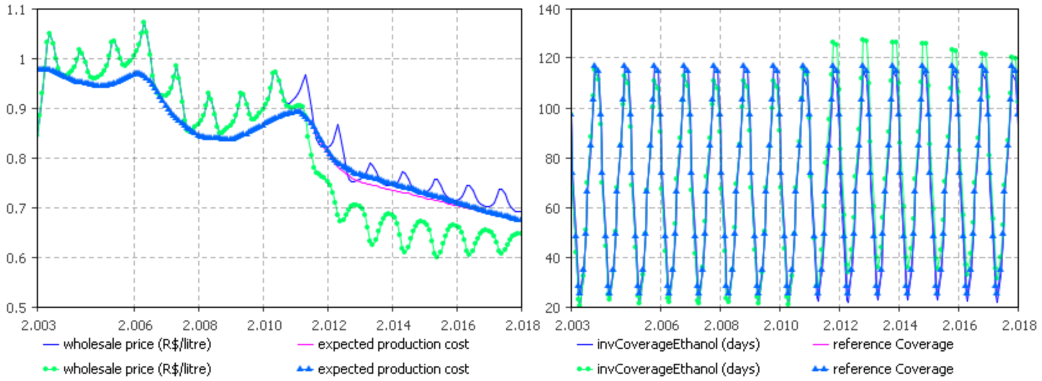
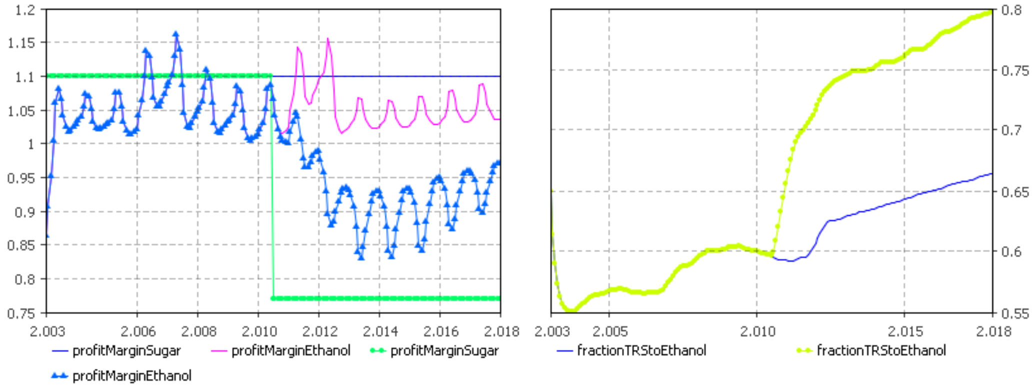


Figure 68. Simulation results: sugar X ethanol after sugar price drop with growing productivity

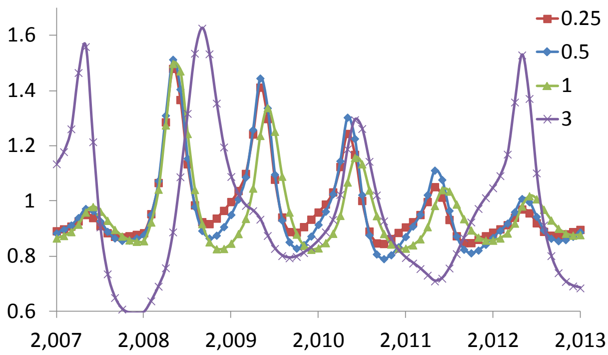


5.3. Sensitivity tests

This section explores how some parameters may influence model behaviour in order to identify the most significant ones. Those should be estimated more carefully as they might drive the behaviour and potentially lead to conclusions that could be inaccurate. Parameters were tested individually using the fixed scenario with the income shock presented in the previous section. The simulations run for 10 years, until 2013, and the 50% shock in income is applied at the beginning of 2008.

The first test is done with variations in the adjustment time for the retail price (Figure 69). For a long time of 3 months, the price behaves erratically even before the shock. This result coincides with our understanding of the system: this parameter should be smaller, as retailers would not wait so long to adjust prices. For the smaller times of .25 and .5 (one and two weeks) the results are almost the same while a time of 1 month slightly changes the shape of the oscillations.

Figure 69. Wholesale price (R$/litre) for different values of Retail price adjustment time (months)



The result supports the use of the chosen value of one week, which also makes sense economically. More than that, the test shows us that if the real value were close to two weeks, that would not make a lot of difference in the results, which contributes to our confidence in the robustness of the model concerning this parameter.

The parameters that determine price sensitivity to cost and inventory coverage are quite important in the model and behaviour can be quite sensitive to them. Figure 70 shows results for variations of the sensitivity to inventory coverage and Figure 71 to cost.

Figure 70. Wholesale price (R$/litre) for different values of Price sensitivity to inv. coverage

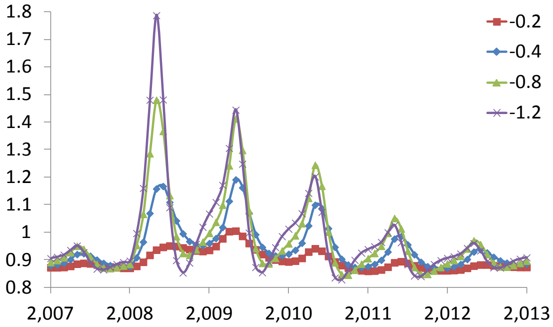
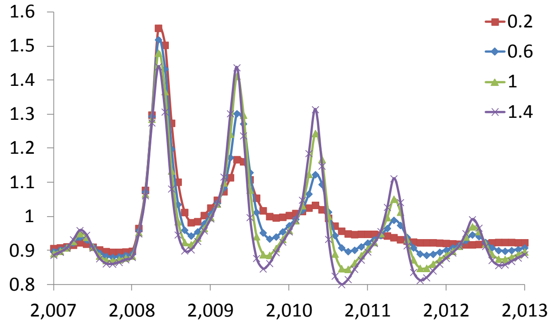


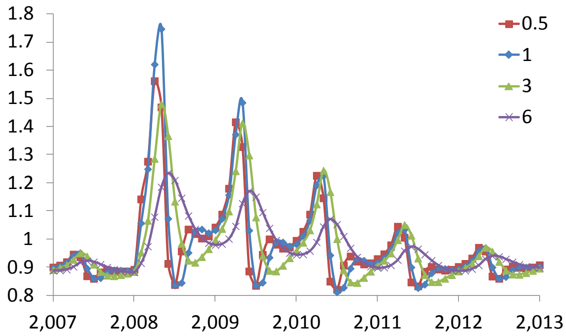
Figure 71. Wholesale price (R$/litre) for different values of Price sensitivity to Cost



Behaviour varies substantially with changes in the sensitivities. For the inventory coverage, with -0.2 the system hardly reacts to the shock, while a value of -1.2 causes the price to jump about 100% and carry big oscillations far into the future. For the cost a small sensitivity causes the price to rise more (slightly) but shortens the oscillations in the future causing the system to stabilize faster after the shock. The chosen values of minus 0.8 and 1 led to better results during the calibration process, but these parameters still deserve close attention as the model is used and improved.

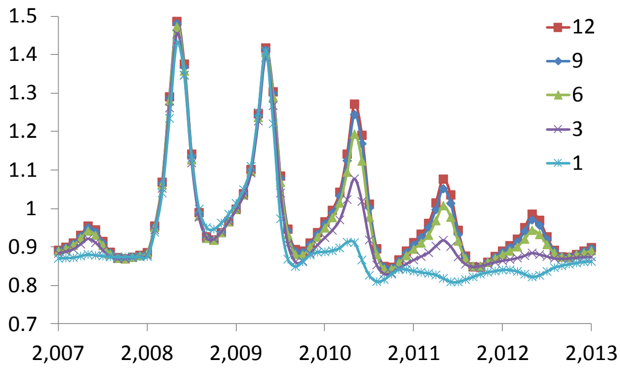
Another variable that deserves attention is the inventory coverage perception time (Figure 72). Short times of two weeks or one month yield sharper responses in price, while longer times cause lower amplitude oscillations. The value chosen in the calibration process is of 3 months, but if this value were to fall to 1 month only it could affect the results considerably.

Figure 72. Wholesale price (R$/litre) for different values of Inv. coverage perception time (months)



On the supply side there are also several parameters that can impact behaviour significantly. Figure 73 shows the test with variations in the parameter Inventory adjustment time. The curves show that the impact is almost the same during the first two years but changes considerably from the third year on, especially for the shorter times of 1 and 3 months. For times of 6 months and higher the difference is very small.

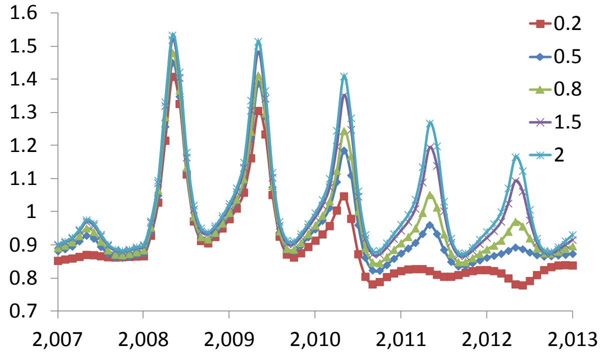
Figure 73. Wholesale price (R$/litre) for different values of Inventory adjustment time (months)



This result gives us confidence that this parameter is not negatively affecting results with the assigned value of 9 months, unless the real value is much smaller than that, which is unlikely.

The parameter Time to plant shows a very similar effect as the inventory adjustment time (Figure 74). The faster the decision to plant is made, the lower the oscillation amplitudes will be, especially in the more distant future. In this case the calibration process chose 0.8 years as a best match. This value is closer to the lower values, so the system behaviour is more sensitive to this parameter, which should be watched closely.

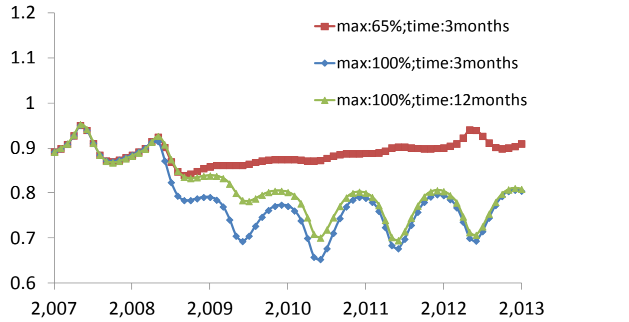
Figure 74. Wholesale price (R$/litre) for different values of Time to plant (years)



Some parameters may be insignificant under certain conditions and highly important in different settings. The limits to the fraction of TRS to ethanol (the production mix) are one example. When running the base scenario, an increase in the maximum fraction of TRS to ethanol will have no consequence, as the fraction never goes close to this maximum. But when testing the negative shock on sugar price, this parameter is highly significant. Figure 75 shows the results of simulations in which the shock was applied for different values of the parameters Maximum fraction and Time to change the fraction.

Now the industry is willing to divert a high amount of capacity to ethanol after the slash in sugar prices. On the first setting, the maximum fraction is 65%, so the effects on ethanol price are small. But when the fraction is set free to go up to 100%, the price of ethanol drops substantially and oscillates more as discussed in section 5.2.4.

Figure 75. Wholesale price (R$/litre) for different values of max fraction TRS and time to change, after sugar price shock of -50%



As discussed previously, this limit is probably close to 65% on the short run, as some mills are dedicated exclusively to one product and even the multi-purpose ones cannot change the production mix too radically. But on the long run the limit might start being relaxed if some of the prices stay low for too long. So this parameter will depend on the time horizon of the simulation.

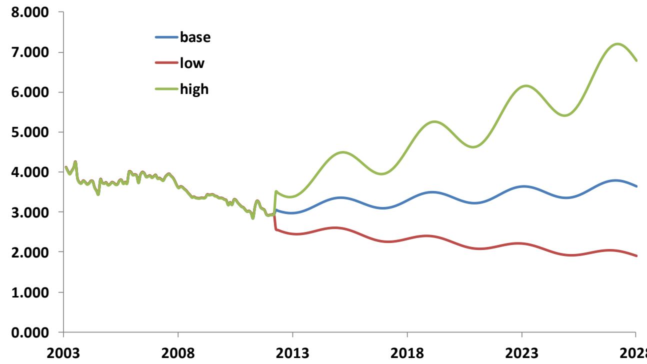
After all the tests, the proposed model, though not highly precise, has proved robust enough at generating sound patterns of behaviour and for that it is useful for its purpose of testing the efficacy and efficiency of various policies under different future scenarios. Next section will cover this topic.

6. Policies and scenario analysis

In order to test different policies, simulations were run for 25 years under different scenarios concerning demand (domestic and for exports), prices of sugar and gasoline and productivity (which is tightly connected to costs). The simulations always start at the beginning of year 2003 and all exogenous inputs are kept at their historical values until march 2012.

Gasoline price in the base scenario is assumed to start from the last year average and to grow 1% per year on average, as the current price is already very low when compared to global prices and to the historical average. The price is also assumed to oscillate with a 4 year period and amplitude equal to 5% of the average value (see Figure 76).

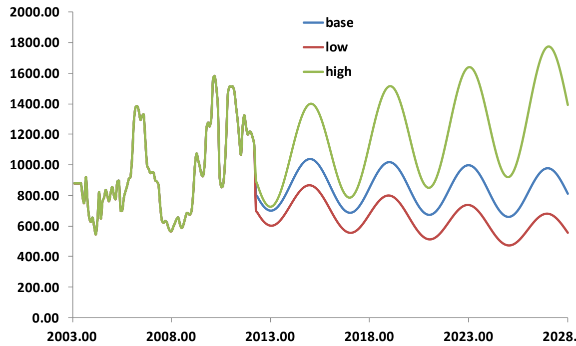
Figure 76. Scenarios for gasoline price (R$/litre)



In the low scenario, the price is assumed to start off 10% lower than in the base setting and to diminish at a rate of 2% per year. In the high scenario price is assumed to start off 10% bigger and to grow 4% per year. It is also assumed to oscillate more, with an amplitude of 10% of the average, as this scenario would be potentially more turbulent.

The sugar price in the base scenario is assumed to start off from an average of the historical prices until around 2008 because the prices in the later years are overly inflated. It is then assumed to decrease 0.5% per year on average due to the diminishing costs. The price is also expected to oscillate with a 4 year period and 20% amplitude (see Figure 77).

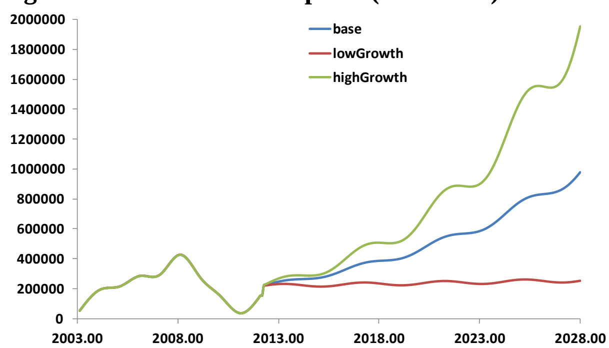
Figure 77. Scenarios for sugar price (R$/tonne)



In the low scenario the price starts off 10% smaller and decreases 2% per year, oscillating with the same frequency and amplitude. In the high scenario the price starts 10% higher and grows 2% per year on average oscillating with a 4 year period and a 30% amplitude.

On the demand side, the scenarios are driven by the GDP per capita and by exports. Exports are assumed to start off from the past average value and to grow in all scenarios. In the base scenario the amount grows 10% per year, with a slight oscillation with period 4 years and amplitude of 5% of the value (Figure 78).

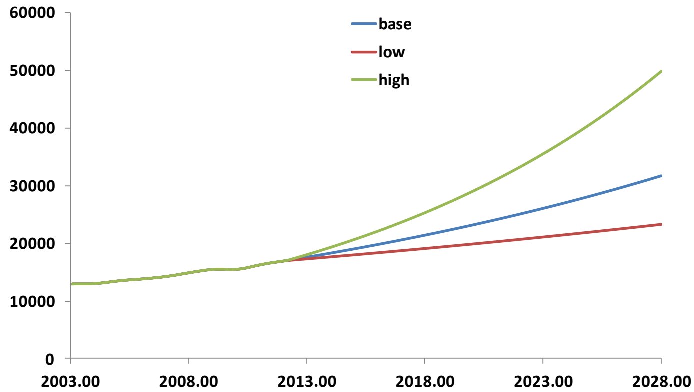
Figure 78. Scenarios for exports (m^3/month)



In the high growth scenario, exported volume grows even faster, with a rate of 15% per year and with a 10% amplitude oscillation. In the low growth scenario the volume is almost stagnated, growing only 1% per year.

GDP per capita starts off from the last value and is also assumed to grow in all scenarios but with varying strength (Figure 79). The base scenario is for a 4%/year growth. Low and high stand for 2 and 7%/year growth rates respectively.

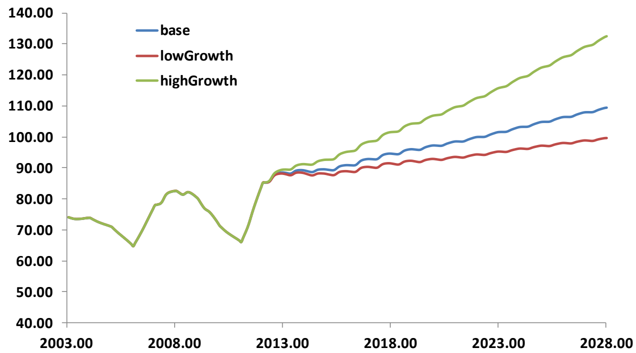
Figure 79. Scenarios for GDP per capita (R$/people/year)



The last exogenous input defined in scenarios is productivity. As shown before, productivity grows with accumulated production of sugarcane according to the learning curve concept. So a growing productivity is actually defined endogenously in the model. But the rate with which it grows, or the experience index, is exogenous. Productivity can grow more or less with accumulated production depending on how much is being invested in research. This parameter is important enough to be defined in different scenarios.

The base scenario was defined during the model development and does not change. The low/high growth scenarios were defined as extensions of the base scenario for simplification. High growth is the base scenario multiplied by a factor with exponential growth of 0.1%/month, while low growth has an exponential rate of -0.05% (Figure 80).

Figure 80. Scenarios for productivity (tonnes/ha)



The demand for sugar is also exogenous and was defined in a single scenario where it grows 2% per year. All the parameters in the model are also exogenous and may have a high influence in the results as shown in the previous section, but they are all defined as constants that do not change during the simulation period. This assumption can of course be challenged.

One could think, for instance, in a scenario where the society and government become more concerned with environmental issues and gradually start using less fuel by prioritizing public transport, bicycles, electric cars etc. In this context, demand for fuel could lower even with a high growth in GDP per capita. For the model this would mean that the constant 'consumption income elasticity' would have to change. If this situation was somewhat probable, this parameter could also be defined in different scenarios.

The analyses here assume that this and other parameters do not change during the simulation time window. The result for prices and cost in the base scenario is shown in Figure 81 and profits in Figure 82.

Figure 81. Price and cost in the base scenario

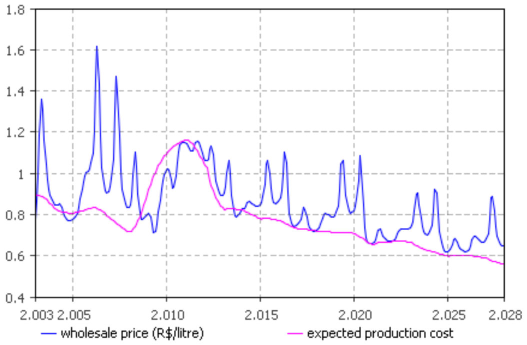
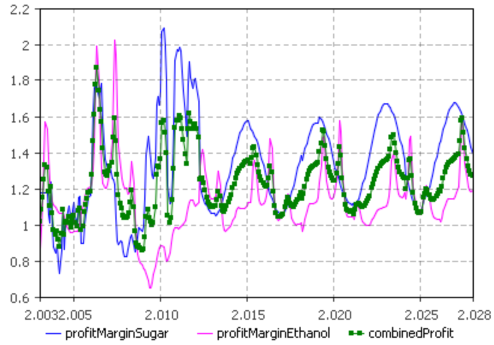


Figure 82. Profits in the base scenario



Prices show a long term downward trend pulled by the costs that are continuously shrinking with the experience curve. Profits seem to follow the oscillations in the exogenous prices of sugar and gasoline after 2012 when all the other inputs are growing smoothly and the only disturbance is a small random variation in productivity from weather effects (Figure 83). The price also oscillates with a frequency dictated by the exogenous inputs. When the sugar price grows capacity is diverted, less ethanol is produced (Figure 84) and its price also grows.

Figure 83. Productivity in the base scenario

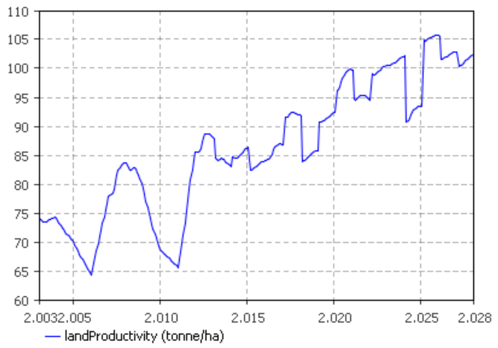
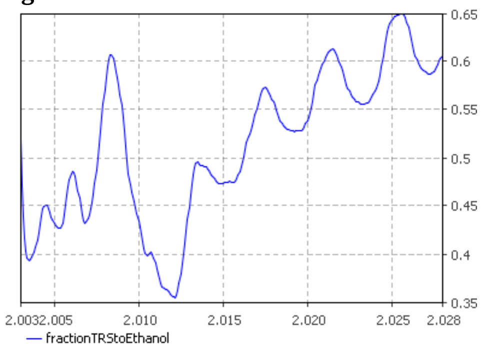
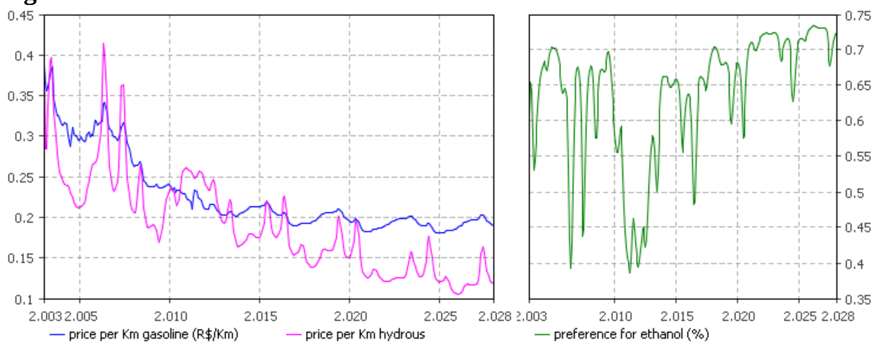


Figure 84. Production mix in the base scenario



When gasoline prices grow, preference for ethanol also grows, putting pressure on demand and leading ethanol prices up likewise (see Figure 85).

Figure 85. Ethanol x Gasoline in the base scenario



But despite the oscillations this scenario is good for the industry. Profit margins are bigger than one throughout the simulation and demand grows circa six fold from 2012 to 2028 (Figure 86). The crops and mill capacity grow after the positive profit forecast and support the surge in demand (Figure 87 and Figure 88).

Figure 86. Demand in the base scenario

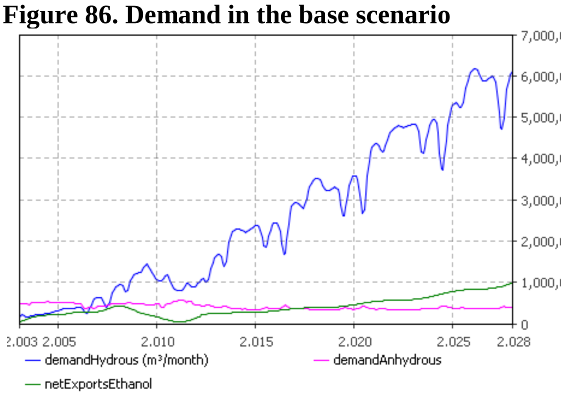


Figure 87. Crops in the base scenario

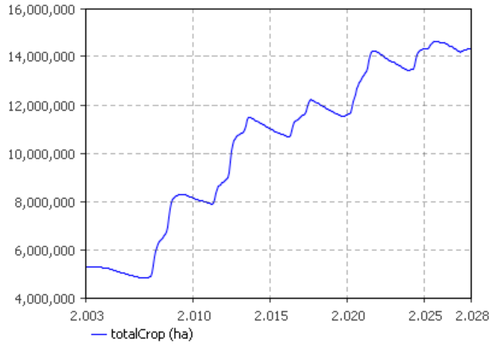
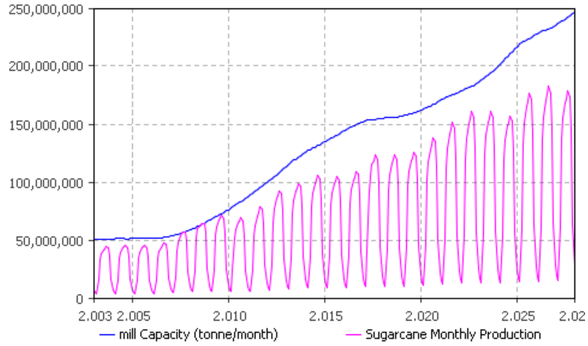


Figure 88. Mill capacity in the base scenario



The situation would be even more favourable in an optimist scenario where prices of sugar and gasoline grow, there is high growth in GDP and exports and productivity grows above historical levels. With these scenarios there is little need for the government to act. But how would the market behave in a more pessimistic scenario?

6.1.Pessimistic scenario

Figure 89 shows prices and cost in the pessimistic scenario and Figure 90 shows profits. Now the industry is incurring persistent periodic losses.

Figure 89. Price and cost in the pessimistic scenario

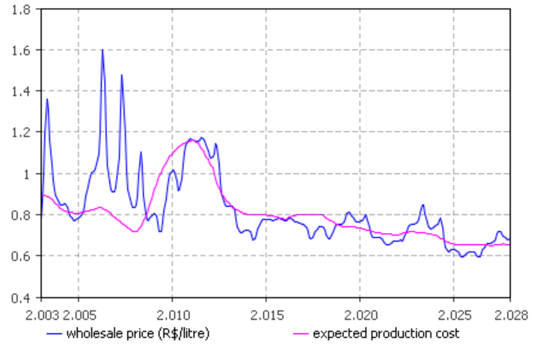
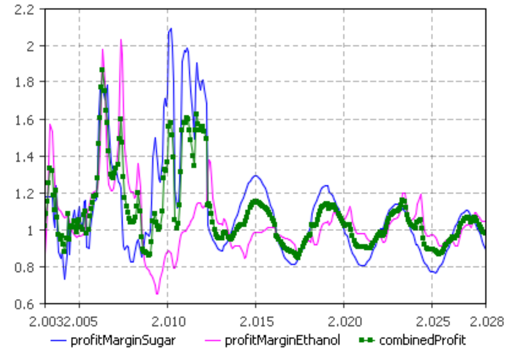
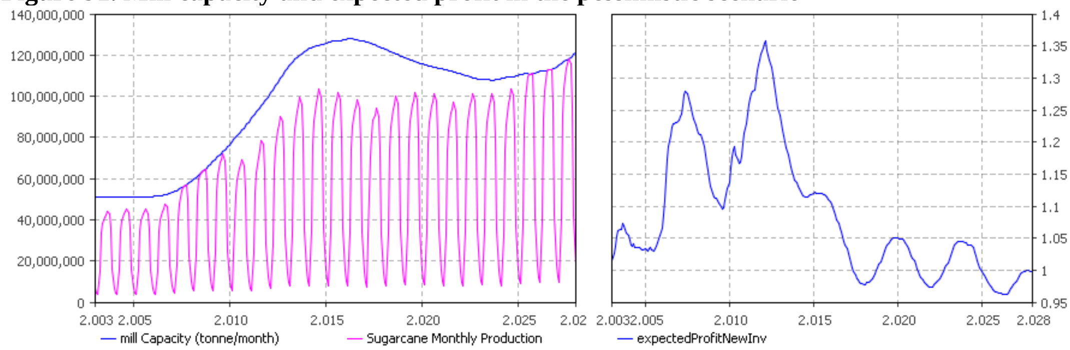


Figure 90. Profit in the pessimistic scenario



The long term expectation of profit is eroded and capacity shrinks (Figure 91) becoming a real constraint for production. But even with this constraint the prices are held down by the low prices of gasoline and sugar.

Figure 91. Mill capacity and expected profit in the pessimistic scenario



The crop area also shrinks with the depressed profits and capacity utilization grows to the maximum (Figure 92), threatening with a shortage of ethanol even though the demand is not growing too much (Figure 93). And to worsen the situation, productivity is growing very slowly (Figure 95), both because the scenario is defined as such and because the weather and age effects are adverse. When profits go down planting stops and the crop area starts diminishing. Without new crops and with lowered renovation, the age of the crops grows widely (Figure 94) and contributes to lower productivity even further. But there are still other mechanisms keeping the prices down. The production mix gradually steers towards ethanol (Figure 96) because sugar prices are low and demand is still growing, though more slowly (GDP per capita still grows and so does the flex fleet). And the preference for ethanol keeps oscillating to counteract changes in demand. So what can the government do in this situation?

Figure 92. Utilization and crop area in the pessimistic scenario

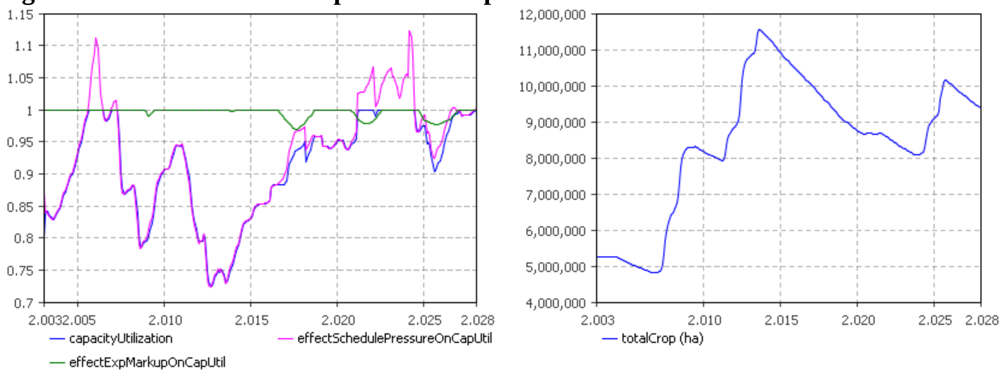


Figure 93. Demand in the pessimistic scenario

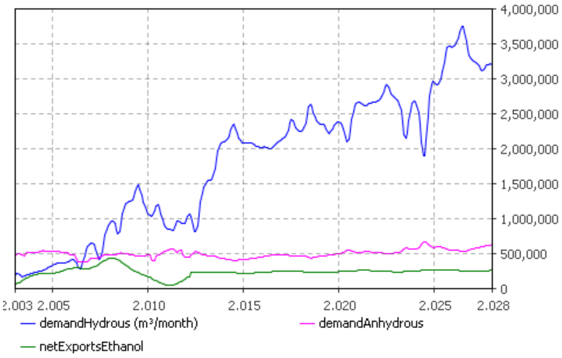


Figure 94. Crops in the pessimistic scenario

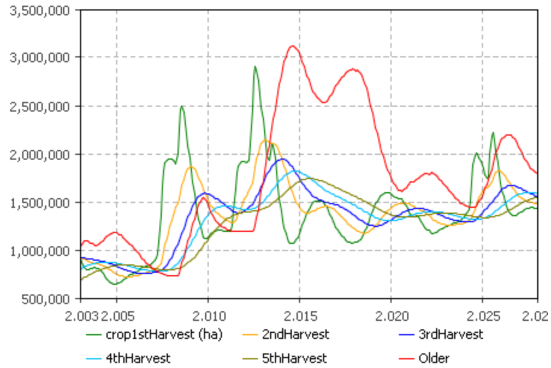


Figure 95. Productivity in the pessimistic scenario

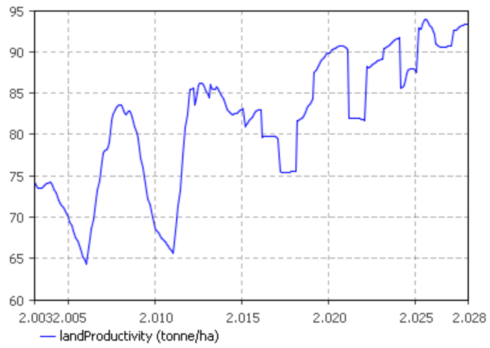
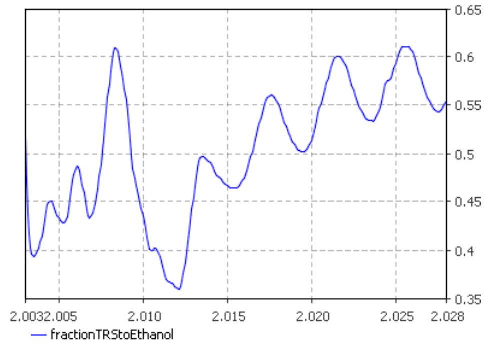


Figure 96. Fraction TRS in the pessimistic scenario



The government can of course attempt to alter some of the scenarios. Apart from attempting to boost economic growth (which is a constant effort) it can try to stimulate exports by setting trade agreements with several countries. It can also devise a strategy to increase productivity with state investments in R&D. Finally, the government has a big influence on gasoline prices via Petrobras and even though the fuel prices are part of a bigger plan related to inflation and economic growth itself, the setting of this price should be part of the government strategy for the sector.

But none of this attempts to change the scenarios constitutes a real short term policy for our purpose because none of them is a variable the government can truly control. For the purpose of our simulation, a policy should be related to a variable the government has the ability to modify in a short enough time in response to changes in the environment. In the model there are two of those variables: the fraction of anhydrous ethanol that goes into gasoline and the subsidies for the sector. The subsidies are mainly tax exemptions and low cost loans, both with the objective of reducing cost to producers and stimulating investments.

On the first test, the government attempts to revert the situation by increasing the anhydrous fraction in gasoline from 20 to 25% (from 2012 until 2028) in an attempt to boost demand. Figure 97 shows the resulting profit compared to the 'no policy' behaviour and Figure 98 shows the resulting demand.

Figure 97. Expected profit after change in anhydrous fraction

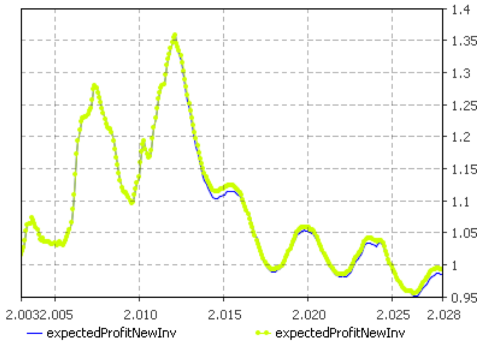
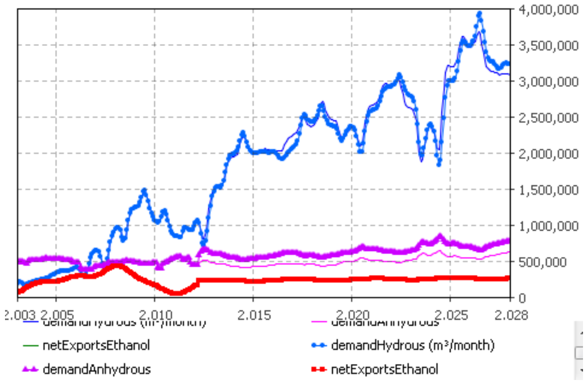


Figure 98. Demand after change in anhydrous fraction



The change is tiny. The increase in anhydrous demand is compensated at some periods by a lower demand for hydrous ethanol and even when total demand grows it does so in a tiny fraction, not enough to change the prices significantly. The fraction was already at 20% and the upper bound of 25% limits the potential effectiveness of this policy. One could assume that the upper limit is actually much bigger, say 50%. In practice that would mean that all gasoline engines would have to be adapted, so this policy is not really feasible, much it might pay to test it as an exercise. The results for profit and demand are shown in Figure 99 and Figure 100.

Figure 99. Expected profit after change in anhydrous fraction to 50%

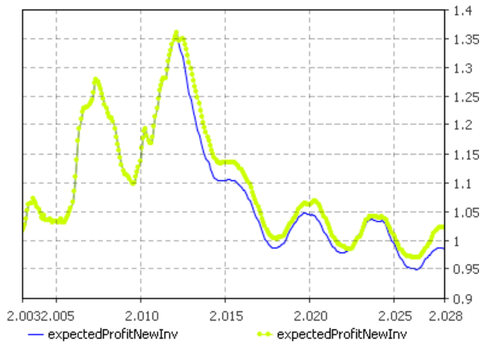
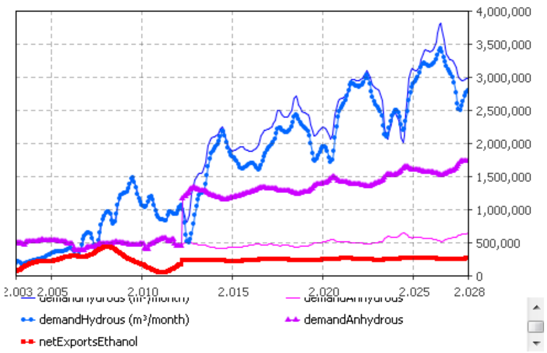


Figure 100. Demand after change in anhydrous fraction to 50%



Now the result is better, but still not so great considering it is an extreme, hardly implementable policy. This result exemplifies policy resistance, a common characteristic of complex systems (Sterman, 2000). Balancing feedback loops act to counteract isolated actions. The increase in anhydrous demand, for instance, may cause the price to grow which, ceteris paribus, will decrease demand for hydrous ethanol.

Subsidies to the industry can be a more effective policy. In the next simulation an incentive amounting to 20% of the costs is applied throughout the whole period from 2012 to 2028. This incentive would probably mean that the whole industry is being permanently exempted from taxes, which is probably unrealistic. But since we are testing an extremely pessimistic scenario, it might be worth testing an extreme policy as well. Figure 101 shows expected profit and Figure 102 shows demand after the subsidies (and compared to the pessimistic scenario without any policies). Now the behaviour improves considerably. Expected profits rise and periods with losses are shorter. Demand for hydrous ethanol also grows significantly now that ethanol prices become smaller (pulled by the lower cost) and boost preference for ethanol over gasoline.

Figure 101. Expected profit after change in subsidies

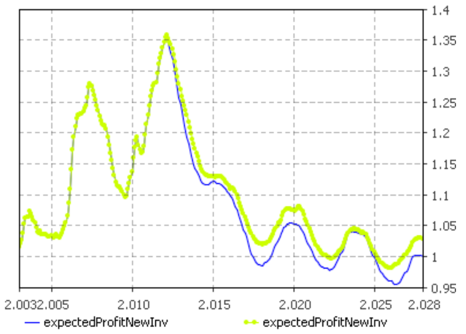
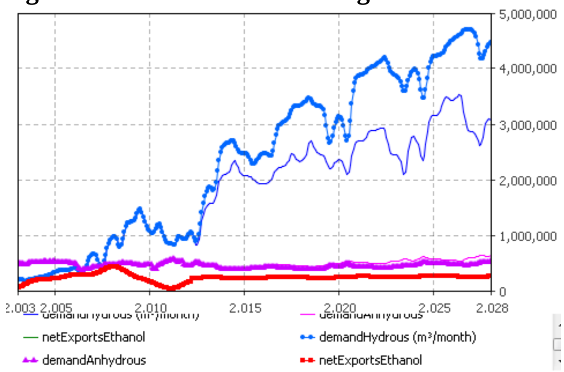


Figure 102. Demand after change in subsidies



Curiously, a very similar effect can be obtained by simply changing gasoline prices back to the base scenario. This result means that from the government standpoint, if there is an option to let gasoline prices grow as in the base scenario, in the long run this would be equivalent to giving the whole industry an incentive amounting to 20% of the costs. Assuming that the government is spending both to keep gasoline prices down (as lost revenues for Petrobras) and to subsidise the industry, it would be saving a considerable amount by letting prices up. The question then is whether the bigger prices will result in higher social costs with inflation, economic stagnation etc. But this speculation is outside the scope of this study.

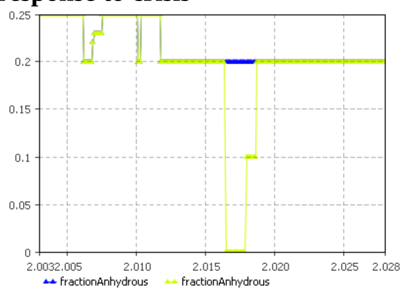
The tests in the pessimistic scenario show how difficult it is to fight structural, persistent problems in complex systems with point measures and short term policies. The conclusion is that if all factors are adverse for a long time, the industry would eventually perish. But the policies might be more effective for temporary crises.

6.2. Transitory crises

In the following tests, shocks are applied for 2 years, starting at month 150 and policies are evaluated concerning their efficacy to attenuate the effects. In the first test, sugar prices jump 100% and productivity lowers 20% (a crisis similar to the one Brazil is facing during 2011).

As expected, capacity is diverted to sugar and productivity affects production negatively reducing the supply for ethanol and even causing a small shortage. Prices jump and demand plummets. An extreme policy is tested then to reduce the anhydrous fraction during the crisis in order to alleviate the demand and reduce hydrous prices. The fraction is reduced to 0 short after prices start increasing and is gradually restored to the original 20% level once prices go back to normal (Figure 103).

Figure 103. Anhydrous fraction in response to crisis



Reducing this fraction to zero is a costly measure, as a new additive to gasoline would have to be procured. It could also make the market nervous with the possibility of it becoming a permanent change as discussed before. But even with this costly measure the results are disappointing (Figure 104 and Figure 105).

The reduction in anhydrous demand translates into more capacity being diverted to sugar and very little into a lower price and higher demand for hydrous ethanol. Also contributes to the lower efficiency, the fact that anhydrous demand represents less and less of the total as the flex fleet keeps growing and so does the hydrous demand. The results seem to reproduce the current development in Brazil where a reduction in anhydrous fraction had little impact in prices. Again the system shows it is resistant to this policy.

High sugar prices can represent a crisis for consumers but not exactly for the industry, as the reduced sales of hydrous ethanol are compensated with sales in the future and with a higher profit for sugar. Next test simulates a distress scenario where sugar prices fall 40% and gasoline prices fall 30% during two years. Ethanol prices also plummet and the industry faces heavy losses during almost the entire period. The impacts in supply are long lasting as crop area and mill capacity shrink with the low profits. Productivity also goes down due to the lower planting and renovation rates that produce older crops as seen before.

Figure 104. Price and cost with response to crisis

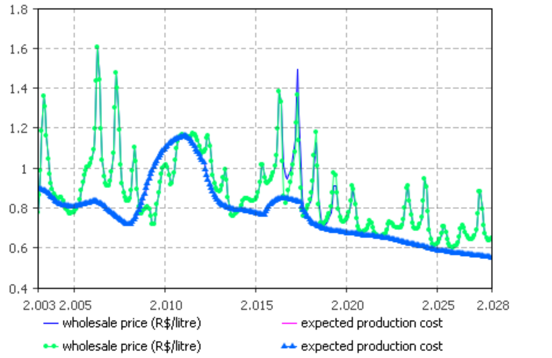
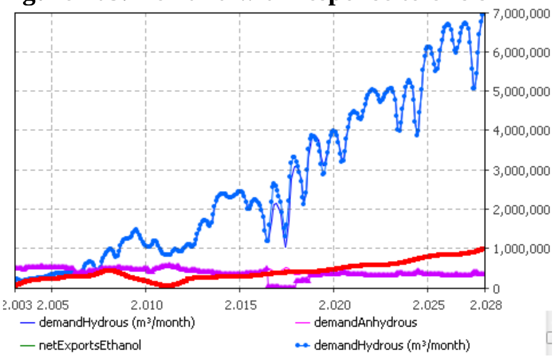


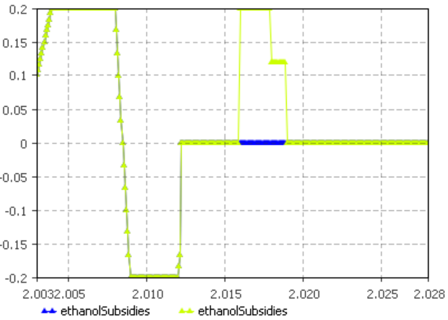
Figure 105. Demand with response to crisis



Now a policy of increasing subsidies during the crisis period is proposed as a response. Incentives of 20% of total costs are applied soon after the prices go down and removed after they settle (Figure 106).

Results are positive. The losses are reduced (Figure 108) and crops and capacity are not reduced as much (Figure 107). Of course the result would be more effective if a bigger incentive could be given.

Figure 106. Subsidies as a response to the crisis



Evidence shows that the industry may face recurring crises with all the global oscillations in sugar and gasoline prices, economic downturns and with eventual climate effects on the crops, but a persistent pessimistic scenario on the long run is unlikely. The most probable development is the base scenario with eventual temporary crises that can be handled by the industry with some eventual help from the government, especially with subsidies and tax incentives.

Figure 107. Impact of policy on mill capacity

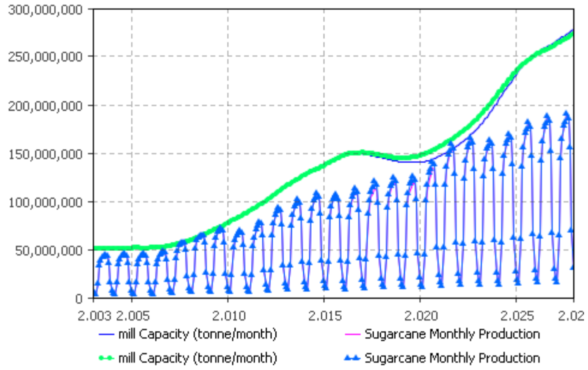
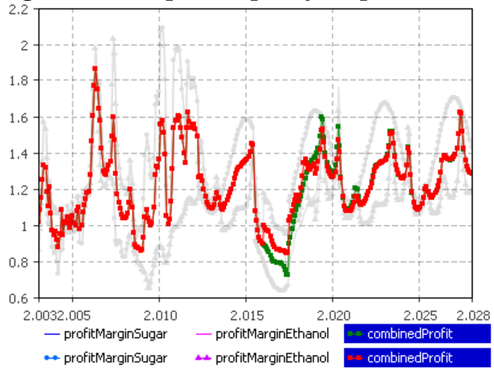


Figure 108. Impact of policy on profits



6.3. Dealing with seasonality

Apart from incentives and the anhydrous fraction, another suggested "policy" by the government is to incentivize (or to enforce) distributors to keep a bigger inventory as discussed in section two. It is worth noting that the size of storage tanks in the mills is not a constraint to production today. The mills do not stock more ethanol because they either lack raw materials, or crushing capacity or because they lack working capital to build too much inventories (Zechin, 2012). In that sense, this measure by the government, from the standpoint of producers, is equivalent to shifting demand: distributors would buy more during the harvest season to build stocks and less between harvests when production stops.

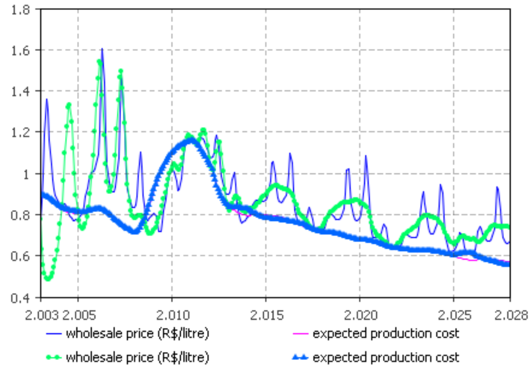
Policy was written with quotes before because, again, this measure does not seem like a variable the government has total control over. Passing a law to enforce the stocking seems like a disproportionate interference on the market and even if it passes, monitoring and enforcement would be expensive and probably ineffective. But even with these difficulties it might be worth simulating the potential effects.

In order to test the effects of shifting the demand one has to consider shifting the expected inventory coverage as well. The mechanics can get extremely complicated as the demand seasonality shifts to behave more like the production seasonality and the expected coverage has to move along. The following test simplifies this exercise by simply testing an extreme setting of no seasonality at all.

If the demand is shifted so it behaves exactly like the production throughout the year, that would be equivalent to not having any seasonality.

Figure 109 shows the price behaviour in this setting compared to when there is seasonality. It is clear that oscillations are smaller without the seasonality, which means that if this policy could be implemented it would be effective in reducing price volatility.

Figure 109. Price in the base scenario without seasonality



Apart from shifting demand, seasonality could also be reduced if the industry did not depended exclusively on sugarcane. This would be a more farfetched approach, but if the mills could process corn in addition to sugarcane, the seasonality would be reduced as corn has different harvest seasons and can be stocked (Porto, 2012).

This and other policies to reduce seasonality seem closer to the efforts to change the scenarios as discussed before. They are not concrete variables the government can control in a short time window. But they, as the scenario changing, can be highly effective to foster and stabilize the industry in the long run and should be part of the government strategy for the sector. The policies of incentives and of changing the anhydrous fraction are less effective or more expensive and should be used only to alleviate the effects of temporary crises.

7. Conclusions

After developing the model, calibrating it and running all the simulations it is evident that this type of exercise is extremely helpful in understanding the system. The resulting model and "flight simulator" can be invaluable tools to assist in decisions.

The simulations show that, as is common with complex systems, the government policies cannot rely on single actions: "you can't do just one thing" (Sterman, 2000, p.22), especially when the conditions are adverse. It became evident that the short term policies (changing the anhydrous fraction in gasoline and giving incentives to the industry) should be complemented by long term policies such as incentivizing research and development and foreign trade.

Simulations also show that the system is highly resistant to policies, which is also common in complex systems with many balancing feedback loops. Changes in the anhydrous fraction in gasoline have little effect in boosting demand as the growth in anhydrous shipments is partly compensated by hydrous reductions and anhydrous becomes less representative as hydrous demand grows.

One important conclusion is that the effect of incentives to the industry is very similar to the effect of letting gasoline prices increase. Considering that the government spends both to keep gasoline prices down (with loss revenues for Petrobras) and to subsidise the mills, a raise in gasoline prices could achieve the same effects (for the ethanol industry) with a considerable drop in government spend.

Reducing the volatility in prices is also a difficult task as the government cannot rely on short term policies for that. The attempts to shift demand can be effective but there is a potential implementation problem. A long term policy to diversify production with the use of corn could be a valid alternative.

The simulations also show some surprising behaviour which deserve further exploration, both for government policies and for other interested parties. An increase in productivity, for instance, was partly compensated by a decrease in planting rate which caused the crops to grow older, resulting in a negative age effect. An increase in productivity for the whole industry also resulted in lower profits as prices fall and consumers benefit more than producers from the lower costs.

Dynamics in the sugar and gasoline markets are shown to be very tightly coupled with the ethanol dynamics. This result is especially novel regarding sugar. Few previous studies relate sugar and ethanol dynamics and when they do, it is suggested that the relationship is weak (Bacchi, 2005). The present simulations show a strong causal effect. The difference could be attributed to long term dynamics which are more easily captured in system dynamics models if compared to econometric ones.

Nevertheless, the relationships are shown to be fundamentally dynamic. A permanent rise in the price of sugar, for instance, is shown to destabilize the price of ethanol, causing higher prices and lower demand in the years following the shock. But in the long run both prices and demand return to original levels. One could interpret it as ethanol prices and demand having a very low elasticity to sugar prices in the long run, but this conclusion would overlook the fact that the effects are dramatic in the short to medium run.

The scenario analysis suggests that despite the current crisis and possible future ones, the forecast is positive and the industry is expected to grow with satisfactory profitability.

7.1. Points for improvement and future research

One of the points for improvement in the model is related to the sugar market. The assumption now is that both demand and price of sugar are exogenous and unrelated which is a rough simplification. Demand for sugar should be modelled as dependent on price and income in a similar way as the demand for fuel (probably with quite different elasticity though). Inventories should also be accounted for and the adjustments added to desired production. The global price will probably be partially influenced by the Brazilian supply as well.

The way costs are defined can also be improved. The feedstock costs depend on a fixed cost per hectare (a simplification). This cost will probably depend heavily on the cost of land which might be partly endogenous: as the crop area grows, land becomes scarce and more expensive. The mills and crops may start expanding to remote areas where the productivity will probably be lower. So the expansion might also have a negative effect in average productivity in the long run, which is not considered in the model.

Sugarcane productivity was defined according to the learning curve but without the influence from age and weather as a simplification. This definition could be revised in following studies. One possibility is that the average TRS per ton of sugarcane might grow when land productivity falls, because then the harvest will be more concentrated on the months with higher sucrose concentration (Porto, 2012). But the weather can also influence the sucrose amount negatively, for instance if it rains in the dry season and the sugarcane blooms, in which case a good chunk of the sucrose is lost to the flowers.

Geographical considerations are also a point for improvement. Brazil is vast and has wide differences between different regions, especially between north and south. Further modelling efforts might benefit from disaggregating demand and supply at least between these macro regions.

Data related to several variables can be better sourced. Crop area, for instance, is not completely clear as different sources are available but with data that seem inflated or not related to sugar and ethanol production. Prices are not available for the whole country. And many estimates could be more reliable if evaluated by experts in the industry.

There is no considerations on the costs to implement policies. One conclusion is that it might be less expensive to let gasoline prices grow, but the amount of savings is not clear, neither is the potential side effect on other macroeconomic variables such as inflation and GDP growth. Eventually the model might even benefit from making part of GDP growth endogenous, as it depends on the price of fuel. But the modeller should also be cautious not to add too much complexity unless it contributes to the purpose of the modelling effort.

As a last suggestion for continued research, further modelling efforts might also consider different stakeholders. It is assumed here that the ethanol industry, though already solid, still needs incentives from the government to thrive completely. In that sense the proposed policies are in favour of the producers. If we think of consumers as a stakeholder that the government needs to "protect", raising gasoline prices might not be the best policy. If we think of environmentalists the aim of the policies can get even more blurry: ethanol is supposed to be a better alternative to gasoline in what concerns GHG emissions, but on the other hand its expansion might put pressure on protected areas. But regardless of political choices, the model and simulations are important tools to support the decision process.

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9. Appendix A - Econometric model of the demand

Demand for "Kilometers" is modelled via a regression on price per kilometer and income per capita as explained in section 4.1. Table 2 displays the historical data used to generate the model and Figure 110 shows the results of the regression analysis with 'log(cons)' (the base 10 logarithm of consumption of kilometers per capita) as the dependant variable.

The elasticities signs are as expected: elasticity to price per kilomter is -0.595 and to income per capita is 0.965. The results are coherent with other econometric studies modelling demand in volume as dependent on price and income and serves the purpose of the present model. Nevertheless, tests suggest that the data might present serial correlation, which calls for further research on this particular model.

Table 2. Historical data for demand model

year	consumption (Km) per capita/year	GDP per capita (R$ of 2010/year)	weighted avg price per Km (R$ 2010)	log(cons)	log(GDP)	log(price)	calc cons.
1997	1,877.70	12,860	0.213	3.274	4.109	-0.671	1,864.11
1998	1,878.93	12,671	0.218	3.274	4.103	-0.661	1,813.19
1999	1,840.32	12,517	0.229	3.265	4.097	-0.640	1,741.12
2000	1,702.86	12,870	0.273	3.231	4.110	-0.565	1,611.71
2001	1,608.94	12,857	0.308	3.207	4.109	-0.512	1,497.90
2002	1,633.12	13,022	0.242	3.213	4.115	-0.617	1,752.29
2003	1,542.07	13,001	0.269	3.188	4.114	-0.570	1,640.18
2004	1,674.28	13,577	0.237	3.224	4.133	-0.626	1,845.88
2005	1,693.21	13,846	0.259	3.229	4.141	-0.586	1,782.30
2006	1,778.04	14,243	0.276	3.250	4.154	-0.559	1,764.47
2007	1,927.19	14,964	0.245	3.285	4.175	-0.611	1,986.26
2008	2,141.30	15,594	0.221	3.331	4.193	-0.655	2,197.60
2009	2,283.82	15,357	0.223	3.359	4.186	-0.651	2,151.97
2010	2,486.59	16,363	0.210	3.396	4.214	-0.678	2,376.79

Figure 110. Results of regression analysis

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-1.094	.813		-1.345	.206	-2.885	.696					
	logGDP	.965	.204	.616	4.741	.001	.517	1.413	.790	.819	.576	.875	1.143
	logPrice	-.595	.157	-.493	-3.794	.003	-.940	-.250	-.711	-.753	-.461	.875	1.143

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.039	2	.020	28.340	.000
	Residual	.008	11	.001		
	Total	.047	13			

Model Summaryb

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.915	.837	.808	.02638	.837	28.340	2	11	.000	.910