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UNDERSTANDING THE LINK BETWEEN ETHANOL PRODUCTION AND FOOD PRICES

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by

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A Thesis

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MAJOR PROFESSOR: Dr. Sajal Lahiri

ABSTRACT: Food prices have increased rapidly in recent years, and so has ethanol consumption. Some studies have claimed that there is a connection between those two. Net exporters of food tend to benefit from higher prices, while regions that are net importers of food, tend to be adversely affected. The large amount of poor countries in the second group justifies an investigation of the causes of increasing food prices. This thesis aims to contribute to the discussion, analyzing, theoretically and empirically, the impact that the diversion of feedstock from food to ethanol production has on food prices. The interaction between food prices and ethanol is first examined in a two-good (food and ethanol), one input (land) theoretical model. The outcome of this model is that an increase in ethanol productivity will have a positive impact on food prices, which is confirmed in the empirical test. We also found that increases in area allocated to produce sugarcane based ethanol in Brazil had depressing effects on relative food prices. No significant conclusion could be found on the effect of the area allocated to produce corn based ethanol in the United States.

DEDICATION

To Carlos…

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CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem

Food prices increased rapidly in recent years, and so has ethanol consumption. Some researchers have claimed that there is a connection between those two.[1] The impact of ethanol on food prices may happen in two ways, either reallocating food crops to fuel production (e.g., sugarcane being allocated to ethanol rather than to sugar) or diverting agricultural land from food crops to energy crops (e.g., wheat crop being substituted by corn).

An increase in food prices is likely to benefit net exporters of this commodity, due to terms of trade gains. However, countries or regions that are net importers of food tend to be adversely affected. The large amount of poor countries in the second group justifies the importance of investigating the causes of high food prices.

The use of biodiesel and ethanol as fuel, also called biofuel, is as old as the invention of the automobile engine. Rudolf Diesel in the early 20th century used peanut oil to power the engine that carries his name. Similarly, Henry Ford intended to use ethanol from corn in his Model T.

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[1] Siwa Msangi et al. (2006), Joachim von Braun (2008).

However, petroleum became the main fuel source because of supply, price and efficiency factors. Blending ethanol in gasoline has happened since the 1930s and vegetable oils continued to be used as fuel during the 1930s and 1940s, although in a much smaller scale. It was in the 1970s, with the second oil shock, that the use biofuels, especially ethanol, was revisited and received incentives from governments of some countries. An example was the Brazilian Alcohol Program (PROALCOOL). However, with the large surplus of gasoline during the 1980s and 1990s, there was no incentive to produce ethanol, and its production reduced drastically, until after 2001, when it regained worldwide attention.[2]

Our goal is to understand the link between ethanol production and food prices. Nonetheless, to better understand the surge in food prices, especially during the past five years, it is necessary to look at its determinant factors. First of all, the increasing trend in global prices was observed in most agricultural commodities, not only food. A combination of factors may be causing this inflation. Among those factors we will be discussing in more detail the accelerated growth in developing countries, the dollar depreciation, increase in energy costs and consequent increase in demand for ethanol.

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[2] Deepak Rajagopal and David Zilberman (2007), Jose Moreira and Jose Goldemberg (1999) and Markku Lehtonen (n.d.).

1.2 Significance of the study

The majority of information available on the specific topic of this thesis is not scientifically supported, and what was, at first, simple curiosity on the subject, unveiled the scarcity of serious research investigating the relationship between ethanol production and food prices. This was the major motivation in developing this study.

This research develops a theoretical framework, demonstrating how the interaction between supply and demand determines the prices and quantities of food and ethanol traded in the market. This model will consider two goods, food and ethanol and one input, land. Ethanol technology is land intensive and within this framework, food and ethanol compete for land and an increase in production of one good implies reducing the production of the other. Additionally, we consider that the farmer has a fixed amount of land and will produce one or both products depending on what proportion of ethanol and food will maximize profit. After observing the equilibrium conditions, comparative statics are applied to predict the effect on food market prices of changes in total land and productivity of ethanol.

The two major ethanol producers are Brazil and the United States (US) and each use a different input in the production process. Brazilian ethanol is based on sugarcane, whereas the United States uses corn. There is a discussion on whether these two production processes have similar impacts on food prices. This research differs from previous studies in that it empirically investigates how sugarcane and corn ethanol affect food prices. It also investigates the role of ethanol productivity on food inflation. This research will benefit scholars by contributing with the literature on food prices and ethanol, bringing a different approach to the matter. In more practical terms, policy makers could also resort to this study in order to gather information that might be valuable in deciding whether or not to invest on alternative energy sources, such as ethanol.

1.3 Research Questions

The purpose of this thesis can be summarized in the following research questions:

1. How changes in ethanol productivity relate with food prices?
2. Are the impacts of sugarcane based ethanol and corn based ethanol on food prices similar?
3. Is the diversion of land from food production to ethanol production affecting world food prices?
4. Are energy costs, growth in developing countries and dollar exchange rates associated with increases in world food prices?

CHAPTER 2

LITERATURE REVIEW

The survey on the existing literature indicated that the amount of research on the core subject of this study is very limited. The vast majority of studies were developed within the last 5 years and most of them do not have a theoretical or empirical support for their argumentation. The main purpose of this thesis is to analyze the impact on food prices of the diversion of land from food production to ethanol production since 1980. Specifically, it intends to investigate whether sugarcane based ethanol and corn based ethanol production have similar impacts on food prices, and to inquiry how ethanol productivity relates to food prices.

2.1 Food Price Inflation

Food prices increased considerably in the past few years. According to the food prices index of the United Nations Food and Agriculture Organization (FAO), there was an increase of almost 30 percent in 2007, compared with 7 percent in 2006. These numbers are slightly different according to the International Monetary Fund (IMF) food prices index, which showed an increase of 15 percent in 2007 and of 10 percent in 2006. Despite the disparity in the amounts, both indexes show a significant increase in food prices for years 2006 and 2007.

An increase in food prices is likely to benefit net exporters of food, due to terms of trade gains. On the contrary, countries or regions that are net importers of food tend to be adversely affected. The large amount of poor countries in the second group justifies the importance of investigating the causes of high food prices. Moreover, people, in general, buy food more often than other items in the consumer price index basket, which contributes to the negative impact of food inflation for both developing and developed countries (Hathaway, 1974).

Joseph M. Kargbo (2000) examined the impacts of monetary and macroeconomic factors on real food prices in eastern and southern Africa. Using a technique of cointegration and error correction modeling, the author tested the long-run relationship between real food prices and the monetary and macroeconomic factors that influence their behavior. The empirical model developed is based on the interaction between supply and demand in the market, which determines food prices. The author uses n simultaneous interdependent equations, representing supply and demand to define the relationship between real food prices, monetary (exchange rate), macroeconomic (trade policy and income per capita) and other variables (domestic food production). The supply and demand equations are then integrated to develop the price-dependent demand equation for food. Stationarity tests were performed, and first-difference was used to correct for nonstationarity of the data. The empirical results suggest that real food prices are jointly determined by income, real exchange rates, money supply, domestic food production and trade policies, with wide implications for food availability and food security.

During the past five years, the increasing trend in global prices was observed in most agricultural commodities and was determined by a combination of factors.[3] First of all, there has been an accelerated economic growth in many developing countries (especially in Asia), which led to a higher demand for food, shifting consumers' preferences from traditional staples to higher-value foods like meat and dairy products, as shown in Figure 1. As a result, demand for grains used to feed livestock[4] also increased.

The depreciation of the dollar is another factor that might be affecting food prices. Exchange rate depreciation has a direct effect on the agricultural sector because it changes the relative prices of tradable and non-tradable goods. Consequently, a country's currency depreciation is generally followed by higher domestic inflation if complementary macroeconomic stabilization policies are not implemented (Kargbo, 2000). As most world commodities are traded in dollar, overall relative food prices are likely to increase due to the cheaper dollar.

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[3] von Braun (2008), Martin Banse et al. (2008), Amani Elobeid and Chad Hart (2007).
[4] Livestock refers to animals raised on a farm and used for profitable purposes, like meat or dairy production.

Finally, there is the surge in energy costs, due to increased demand, which led to a raise in commodity prices in 2005 and 2006, as can be observed in Figure 1. Despite demand pressure, there was no effort in increasing the supply of oil by the OPEC countries,[5] which resulted in record high oil prices on the first half of 2008.[6] High oil prices led to more expensive agricultural production due to higher costs of transportation and inputs, such as fertilizers and pesticides, contributing even more to the inflationary pressure on food prices.

The increase in oil prices also worked as an incentive towards alternative forms of energy worldwide. Leading the way were Brazil and the US. Brazilian sugarcane producers shifted production from sugar to ethanol in 2006 and 2007, according to the data provided by that country's Ministry of Agriculture. Similarly, US farmers extensively switched their cultivation from food to biofuel feedstock,[7] especially corn (Robert Wisner, 2007).

[5] Christopher Portman (2007).
[6] This scenario was reversed with the world financial crisis that reduced demand for oil considerably during the second half of 2008.
[7] Feedstock refers to the raw material used in the conversion process. It can be a crop, crop residue, or agricultural and rural waste. The main kinds are sugar, starch, oil seeds and perennial grasses (Rajagopal and Zilberman, 2007).

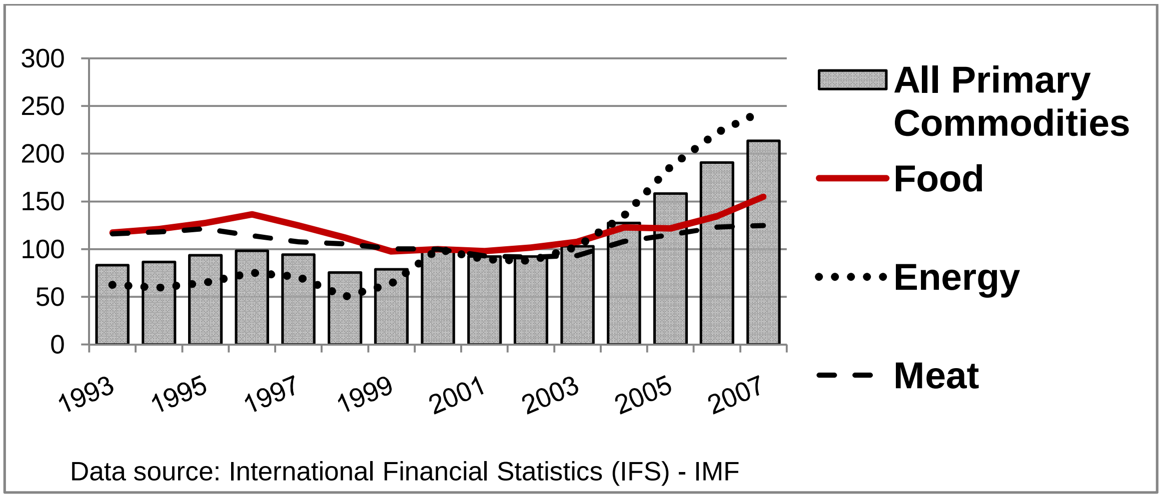

Figure 1 - Commodities Price Index

2.2 Linking Food Prices and Ethanol

The link between ethanol production and food prices is the first big discussion proposed by this study and the available literature found that accelerated growth in ethanol (and biodiesel) supply, if not followed by an increase in crop productivity, is likely to increase food prices considerably.[8] The impact of biofuels on food prices may happen in two ways, either reallocating food crops to fuel production (e.g., sugarcane being allocated to ethanol rather than to sugar) or diverting agricultural land from food crops to energy crops (e.g., wheat crop being substituted by corn).

The accelerated increase in food prices in the past couple years, as described by Marc Plant (2008), is a result of long-term structural influences and short-term factors. Increased biofuel demand, according to him, is just one of the determinants. Long-term factors are the rising

[8] Msangi et al. (2006).

demand for food, decreased investment in agriculture, low prices and distortions in agricultural markets. The short-term factors, which could be observed especially after 2004, are bad harvests, increasing overall demand due to fast growing developing countries, high oil prices driving up the cost of agricultural inputs, like fertilizers, and transport, and rising biofuels production. Finally, food prices are expected to stabilize in the short-run but are likely to remain higher than in the past.

Bruce A. Babcock (2008) identifies two drawbacks from producing biofuels from feedstocks that are diverted from food production or that are grown on land that could grow food crops: (a) increase in food prices and (b) inefficiency in reducing greenhouse gas emissions. The second drawback conflicts with Granda et al. (2007), according to whom greenhouse gas emissions tend to decrease.

Focusing in the impact of biofuels on food prices, Rajagopal and Zilberman (2007) built possible scenarios in case more resources are directed to biofuel production. According to their research, developed regions such as the EU and the US will experience price increases but may be able to absorb the price rise more easily than developing countries. The food processing industry will be negatively affected due to higher input costs and lower demand for food. Net food importer developing countries would be negatively affected due to higher food prices, regardless of whether they adopt biofuels or not. Finally, if biofuel crops are cultivated only on unused or marginal lands, with little competition with food crops, the impacts on food prices tend to be minimal. In reality, however, biofuels may still compete for other resources, such as water or labor, thus impacting food production.

According to Wisner (2007), the state of Iowa (largest producer of corn in the US) may need to increase corn production by 70-80 percent until 2011, in order to meet the increased demand for corn from the biofuel industry, among others. The author states that pushing more croplands into corn will reduce the supply of food crops, such as wheat, soybeans, grains, and other crops, resulting in an increase in crop prices. He emphasizes that corn prices in 2007 were already more than double compared with 2006. Finally, the author presents some factors that could alleviate the impact on food prices, which include lower oil prices, reduced government subsidies for corn ethanol and a fast development of technology to convert cellulosic material and waste in ethanol. It is important to highlight that the US is one of the largest corn producers in the world and an increase in domestic prices is likely to impact international corn prices.

Mark W. Rosegrant (2008) examines the impact of alternatives to current biofuel demands using the International Food Policy Research Institute's (IFPRI) IMPACT model,[9] which consists in a partial equilibrium modeling framework. It captures the interactions among agricultural commodity supply, demand, and trade for 115 countries and the world

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[9] International Model for Policy Analysis of Agricultural Commodities and Trade.

(to close the model). Demand for food, feed, biofuel feedstock, and other uses are also included in the model. He runs three separate analyses. For the first analysis, he evaluates the recent food price evolution with and without high biofuel demand and finds that the increased demand during the period 2000-2007 is estimated to account for 30 percent of the increase in weighted average grain prices. The second analysis refers to the impact of a freeze on biofuel production from all crops. With that in place, corn prices are expected to decline by 6 percent by 2010 and 14 percent by 2015. Price reductions are also expected for oil crops, cassava, wheat, and sugar. The third analysis, which consisted in abolishing biofuel demand from food crops after 2007, resulted in a deeper decline in the prices of key food crops: 20 percent for corn, 14 percent for cassava, 11 percent for sugar, and 8 percent for wheat, everything by 2010. The study’s final conclusion is that if biofuel production continues to expand, calorie availability in developing countries is expected to grow more slowly, and the number of malnourished children is projected to increase, even though biofuels lead to higher farm income and adds agricultural value in those regions. Nonetheless, this author does not consider the impact of high oil prices on food prices.

2.3 The Ethanol Market

The interest on ethanol markets increased considerably in recent years and, although other sources of renewable energy (e.g., solar, aeolic) exist, technological improvements are necessary before most of these resources can be used in large scale. That is not, however, the case of biofuels (e.g., ethanol and biodiesel), which have been used in many countries as an alternative to fossil fuels, such as gasoline and diesel. Brazil and the US are the leading producers and consumers of biofuels, and this is the reason why this study focuses on the ethanol production involving both countries.[10]

Economics, politics, and the environment are identified as the main driving forces for the increase in biofuels demand.[11] The economic viewpoint is related with high fossil fuel prices; if oil prices were to fall below a certain level there would be no economic incentives to invest on biofuels. The political incentive is related with energy security, and reflects the recent instability in the regions of the world where most oil reserves are concentrated. Benefits to the environment, although controversial, are the third driving force for implementing an infrastructure based on biofuel.[12] Other studies complement this discussion by adding other forces that also play an important role in the

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[10] According to Claudia F Bruhwiler and Heinz Hauser (2008) ethanol is the major biofuel produced at the present and according to UNICA (2008), Brazil and US account for 72% of world's ethanol production.
[11] Cesar B. Granda et al. (2007).
[12] Further discussion on the environmental impacts of biofuels can be found on: Rajagopal and Zilberman (2007) and José Goldemberg et al (2008).

increased interest in biofuels. These forces are: (a) social and (b) economic pressures for rural development and job creation, the need to develop new markets for agricultural products and the replacement of methyl tetra butyl ether (MTBE) by ethanol as octane enhancer.[13]

The biofuel of focus in this study is ethanol, which presents considerable heterogeneity in production. As described in Walter et al. (2007), it can be produced from fossil fuel feedstocks, like petroleum derivatives, or from biomass. The production from biomass is the one that matters here. This type of production is based on carbohydrate-rich raw materials, which may be classified in three groups: feedstock rich on sugar (e.g., sugarcane), starches (e.g., corn, potatoes) and cellulosic materials (e.g., wood, rice straw). Table 1 presents the biofuel technology matrix for both ethanol and biodiesel. Cellulosic material (third group represented in Table 1) is considered the most sustainable source for ethanol; however, it is not yet commercially available. Production of ethanol from sugarcane is the most common in Brazil, whereas in the United States, starch obtained from corn is mostly used.[14]

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[13] Frank Rosillo-Calle and Arnaldo Walter (2006), Amani Elobeid and Simla Tokgoz (2006) and Arnaldo Walter et al. (2007).

[14] For perspectives on Ethanol fuel see Cesar B. Granda et al. (2007), Rajagopal and Zilberman (2007), Daniel G. de La Torre Ugarte et al. (2007), Arnaldo Walter et al. (2007), Walter et al (2008).

Table 1 – Biofuel Technology Matrix

Feedstock type	Type of biofuel	Major end-use	Crops in temperate climes	Crops in tropical climes	Conversion technology	Tech. maturity	Comm. Maturity
Sugar/ Starch	Ethanol	Transport	Corn, Sugar beet	Sugar-cane	Fermen-tation	High	High
Oil Seeds	Bio-diesel	Transport	Soy, Rapeseed	Palm, Jatropha	Trans-esterification	High	High
Cellulose	Ethanol	Transport	Switch grass	_	Enzymatic or acid hydrolysis	Low	Nil

Source: adapted from Rajagopal and Zilberman (2007)

The US policy on ethanol focuses in protecting the domestic production derived from corn, which raises a discussion on efficiency.[15] To be a beneficial fuel source, ethanol must require less energy in its production than it generates. Timothy Searchinger et al. (2008) used a worldwide agricultural model to estimate emissions from land-use change in the US and found that corn-based ethanol, instead of producing greenhouse gases (GHG) savings, nearly doubles greenhouse emissions.

A less negative view is presented by Granda et al. (2007). Their study found corn ethanol to have a positive net energy, but only by a small margin, and even though it reduces emissions of GHG,[16] it may increase other emissions if coal is used in the production process. On the other hand, according to the same study, the environmental benefits of sugarcane ethanol cannot be refuted. In the Brazilian case, the positive energy balance of sugarcane ethanol production is due, in part, to limited

[15] Harry de Gorter and David R. Just (2007) and Claudia F. Bruhwiler and Heinz Hauser (2008) present a critical view of the US ethanol policy.
[16] For a discussion on GHG efficiency see Richard Doornbusch and Ronald Steenblik (2007).

use of fossil fuels in the production process and to the hydropower-based Brazilian energy matrix.[17] There are other concerns regarding the massive use of ethanol, such as deforestation, impacts on biodiversity and the fact that ethanol production, in some cases, uses an important source of feedstock, which has been claimed to be pushing food prices up, as discussed previously.

Rajagopal and Zilberman (2007) summarized the potential for ethanol production (Table 2), allowing to draw a comparison among different crop sources for ethanol. Table 2 considers four important world crops with real and estimated production values. The second column represents the total area planted with each crop, followed by the average yield in tons per hectare and the global production in million tons. The four last columns are estimations made by the authors in case the total production of each crop was used to produce ethanol. Columns 5 and 6 give an idea of each crop's efficiency in producing ethanol, with respect to the amount of output (tons) and area planted (hectare). Sugarcane yields more liters of ethanol per hectare planted and is more than twice ahead of the second crop, corn. Column 7 is a theoretical estimation of the maximum quantity of ethanol that could be produced and its proportion to the total amount of gasoline supply for year 2003 is depicted in column 8. According to column 8, utilization of the total world supply of

[17] José Goldemberg et al (2008) do a systematic analysis of the sustainability of sugarcane ethanol produced in Brazil, including discussions on land competition between ethanol and food crops, impacts of monoculture on biodiversity and the existence of abusive working conditions in the sugarcane sector.

these 4 crops for ethanol production would account for only about 51% of the global gasoline consumption in 2003.

Table 2 – Potential for ethanol production from major crops

(1) Crop	(2) Global acreage (million hectares)	(3) Average yield (tons/ hectare)	(4) Global production (million tones)	(5) Conversion efficiency (liters/ tone)	(6) Land intensity (liters/ hectare)	(7) Max. ethanol (billion liters)	(8) Supply as % of 2003 global use of gasoline*
Wheat	215	2.8	602	340	952	205	12%
Rice	150	4.2	630	430	1806	271	16%
Corn	145	4.9	711	402	1968	285	17%
Sugarcane	20	65	1300	70	4550	91	6%

*Global gasoline use in 2003 was 1,100 billion liters
Source: adapted from Rajagopal and Zilberman (2007)

The consolidation of an international ethanol market seems interesting for many, especially for developing countries with comparative advantages in ethanol production.[18] However, ethanol trade is highly affected by protectionist policies, which prevents the development of the ethanol industry in countries with comparative advantages and encourage its production where it is more expensive.[19] The US has several examples of government policies supporting domestic production of ethanol, which include subsidies, tariffs and federal and state legislations.[20] The most recent legislation is the Food, Conservation and

[18] The United Nations Foundation launched a program to promote the production and use of biofuels by developing countries, given the potential this market has on alleviating poverty, creating rural development, reducing dependency on imported oil and increasing access to modern energy services. (UN Foundation, 2006). http://www.unfoundation.org/programs/environment/climate_change.asp. Accessed in July 2008.
[19] Peter Hazell and R. K. Pachauri (2006).
[20] Extensive discussion on US federal and state legislation on biofuels can be found at Amani Elobeid and Simla Tokgoz (2006), Doug Koplow (2006), Walter et al. (2007) and FAPRI (2008a,b).

Energy Act (FCEA), also known as the 2008 farm bill. This act extends the $0.54 per gallon ethanol tariff until 2010 and reduces the tax credit for ethanol blended on gasoline from the current US$0.51 per gallon of ethanol to US$0.45 per gallon in 2009 and 2010.[21] Table 3 summarizes biofuel policies and targets for the four major producers of biofuels.

Table 3 – Production, future targets and policies in some countries[22]

Country	Current capacity	Future targets	Biofuel sources	Biofuel policies	Trade policy for biofuels
United States	18.4 billion liters of ethanol (2006), 284 million liters biodiesel (2005)	28 billion liters of ethanol by 2012 and 1 billion liters of cellulosic ethanol by 2013	corn and in future cellulosic sources	excise tax credit, mandatory blending, capital grants, vehicle subsidies	import tariff of $0.1427 per liter ethanol plus ad valorem tariff with some exemption for Caribbean countries
Brazil	17.5 billion liters (2006)	25% blending of ethanol (in effect), 2.4 billion liters of biodiesel by 2013	sugarcane, soybean	Mandatory blending, capital subsidies, vehicle subsidies	20% ad valorem import tariff on ethanol (waived in case of domestic shortage)
European Union	3.6 billion liters of biodiesel (2005), 1.6 billion liters of ethanol (2006)	5.75 percent of transportation fuel on energy basis by 2010	rapeseed, sunflower, wheat, sugar beet and barley	excise tax credit (beginning to be phased out), carbon tax credit, mandatory blending, capital grants and funding for R&D	ad valorem duty of 6.5% on biodiesel and import tariff of $0.26 per liter on ethanol (latter is waived for some categories countries)
China	1.2 billion liters of ethanol (2006)	Data not found	Corn, cassava, sugarcane	subsidies and tax breaks for non-grain feedstock	import tariff of 30% on ethanol

Source: adapted from Rajagopal and Zilberman (2007)

Policies like this may cause distortions in the ethanol market, and very few studies have tried to quantify such distortions, generally investigating a particular policy or program through theoretical models or using simulation.[23] For example, the Food and Agricultural Policy

[21] A detailed investigation on the effects of the FCEA can be find at FAPRI (2008b)
[22] These are policies that were in effect by the time this thesis was written and due to nature of legislations, may be revoked or altered by the responsible authorities.
[23] Paul W. Gallagher (2007b)

Research Institute (FAPRI)[24] has examined the potential consequences of the Energy Independence and Security Act (EISA) of 2007, which established new mandates for the use of biofuels in the US. The impacts of selected provisions of EISA are estimated by comparing a set of baseline projections that do not include the provisions with a scenario that does. The main findings are that the mandates result in more ethanol and biodiesel production than would otherwise exist. Also, the increased biofuel production raises the demand for corn and vegetable oil, which results in higher prices for corn, soybeans and most other agricultural commodities. Finally, higher crop prices translate into reduced costs of government farm programs and higher levels of income for crop producers.

A detailed international model for ethanol was created by Elobeid and Tokgoz (2006) in order to investigate the impact of trade liberalization and removal of the US federal tax credit in the Brazilian and US ethanol markets. It consists of a non-spatial, multi-market model, with a number of countries/regions, including a rest-of-the-world aggregate to close the model. Ethanol production, use and trade between countries/regions are specified and linkages to the agriculture and energy markets (e.g., U.S. crops, world sugar, and gasoline) are incorporated into the model. Their results suggest that the removal of trade distortions in the US will raise world ethanol prices (defined as the

[24] FAPRI (2008a)

Brazilian ethanol price) driven by the increase in demand. US domestic ethanol prices, however, would decrease. Brazil, with its comparative advantage of low-cost ethanol production, would benefit. Other markets would also be affected, such as the sugar market and the corn market and its by-products.

CHAPTER 3

FOOD PRICES AND ETHANOL:

A THEORETICAL FRAMEWORK

3.1 Introduction

Food prices are simultaneously determined by the interaction of producers and consumers in the market. Demand and supply of food also depend on what happens in the market for other products. In this case, the other product is ethanol. In this chapter, we develop a simple model to examine how the interaction between supply and demand determines the prices and quantities of food and ethanol traded in the market. After observing the equilibrium conditions, comparative statics are applied to predict the effect on food market prices of changes in total land and productivity of ethanol.

The model considers a small closed economy with two goods: food and ethanol. We do not explicitly consider what crop is being used to produce ethanol. The representative farmer produces both goods. The representative consumer always needs a combination of both, given that food is necessary for nutrition and ethanol for transportation. It is defined that the farmer has a fixed amount of land and will produce one or both products depending on what proportion of ethanol and food will maximize profit. Ethanol technology is land intensive and within this framework, food and ethanol compete for land and an increase in production of one good implies reducing the production of the other.

3.2 The Model

In this model, there are two outputs, food and ethanol and one input – land. Ethanol is defined as the numeraire good, and its price set to unity ($p_E = 1$). The price of food is p_F and the remuneration for the land is the rent, defined as w. The production functions for food and ethanol are defined as follows:

$$F = f(L_F) = L_F^{\gamma} \tag{1}$$

$$E = e(L_E) = A \cdot L_E^{\delta} \tag{2}$$

where A is the total factor productivity, or the productivity of land used to produce ethanol. The parameters γ and δ are the output elasticities of land, determined by the available technology. These parameters also define the returns to scale of food and ethanol production. In this model, decreasing returns to scale are assumed, implying that $0 < \gamma < 1$ and $0 < \delta < 1$. The market is assumed to be perfectly competitive.

The producer problem

We consider the farmer's profit maximization problem, subject to the constraint that the amount of productive land is fixed. Profit can be defined as the revenue from food and ethanol production minus the production costs and is given by

$$\pi = p_F L_F^{\gamma} - wL_F + p_E A L_E^{\delta} - wL_E \tag{3}$$

The farmer wants to maximize profit but is constrained by the amount of land available $L_F + L_E \leq L_T$, where L_T is the total amount of land. Therefore, his decision is limited to what proportions of food and ethanol to produce in order to increase revenue. Defining $L_F = L_T - L_E$, and inserting it in equation (3) we get the constrained profit function

$$\pi = p_F (L_T - L_E)^{\gamma} - w(L_T - L_E) + p_E A L_E^{\delta} - wL_E \tag{4}$$

The first order condition, defined by $\frac{\partial \pi}{\partial L_E} = 0$, results in the implicit function

$$\frac{\delta A L_E^{\delta-1}}{\gamma (L_T - L_E)^{\gamma-1}} = p_F \tag{5}$$

No interpretation can be drawn from an implicit function and we proceed to take the total derivative of (5). After isolating the change in land used to produce ethanol we find the following equation

$$dL_E = \frac{\gamma (L_T - L_E)^{\gamma-1} dp_F + p_F \gamma (\gamma - 1)(L_T - L_E)^{\gamma-2} dL_T - \delta L_E^{\delta-1} dA}{\delta A(\delta - 1) L_E^{\delta-2} + p_F \gamma (\gamma - 1)(L_T - L_E)^{\gamma-2}} \tag{6}$$

From equation (6) we can establish the relationship between the variables. The denominator will always be negative, hence, dL_E is inversely related with dp_F and directly related with dL_T and dA . As the price of food increases (dp_F), land allocated to produce ethanol (dL_E)

decreases. This is consistent with our expectations that higher food prices would work as an incentive to produce more food, rather than ethanol. An increase in total land (dL_T) implies more land will be used to produce ethanol (dL_E), and finally, higher ethanol productivity (dA) will result in more land allocated to produce ethanol (dL_E).

To conclude the supply side of this optimization problem, we take the total derivative of (2) to find the ethanol supply equation

$$dE = L_E^{\delta} dA + \delta A L_E^{\delta-1} dL_E \tag{7}$$

From equation (7) we see that ethanol supply is directly related with ethanol productivity and with the amount of land allocated to produce ethanol. In other words, if ethanol productivity increases, there will be a higher ethanol supply. The same will happen if more land is allocated to produce ethanol. Both results are very straightforward.

Substitute equation (6) into equation (7) to get

$$\begin{aligned} dE = &\left(L_E^{\delta} - \frac{\delta A L_E^{\delta-1} \delta L_E^{\delta-1}}{\delta A(\delta-1)L_E^{\delta-2} + p_F \gamma(\gamma-1)(L_T - L_E)^{\gamma-2}} \right) dA \\ &+ \delta A L_E^{\delta-1} \left(\frac{\gamma\left(L_T - L_E\right)^{\gamma-1}}{\delta A\left(\delta-1\right) L_E^{\delta-2} + p_F \gamma\left(\gamma-1\right)\left(L_T - L_E\right)^{\gamma-2}} \right) dp_F \\ &+ \delta A L_E^{\delta-1} \left(\frac{p_F \gamma\left(\gamma-1\right)\left(L_T - L_E\right)^{\gamma-2}}{\delta A\left(\delta-1\right) L_E^{\delta-2} + p_F \gamma\left(\gamma-1\right)\left(L_T - L_E\right)^{\gamma-2}} \right) dL_T \end{aligned} \tag{8}$$

We substituted change in land allocated to ethanol (6) into the ethanol supply equation (7). Now we have ethanol supply in terms of ethanol productivity, price of food and total land. Analyzing equation (8) we see that the denominator will always be negative, therefore, dE is directly related with dA and dL_T, and inversely related with dp_F. The interpretation here is straightforward as well. Higher ethanol productivity leads to more supply of ethanol (as we saw with equation (7)). If the price of food increases, the farmer will have a higher incentive to produce food, rather than ethanol, hence ethanol supply will decrease. Finally, if the farmer gets a larger share of total land, keeping everything else fixed, he will allocate some of the extra land to produce ethanol, hence leading to a higher ethanol supply.

The consumer problem

Next, we consider the problem of determining the consumer's utility maximization subject to a budget constraint. The consumer wants a basket of goods containing food for nutrition and ethanol for transportation, in a combination that will maximize his utility. This can be formally stated as

$$\max U = F^{\alpha} \cdot E^{1-\alpha} \tag{9}$$

where $0 < \alpha < 1$. The consumer is subject to $p_F F + p_E E = b$, where b is the total budget or income. The Lagrangean of the problem is

$$L = U + \lambda(b - p_F F - p_E E) \tag{10}$$

From the Lagrangean we derive the marginal utilities of food and ethanol

$$\frac{\partial L}{\partial F} = 0 \Rightarrow \alpha F^{\alpha-1} E^{1-\alpha} - \lambda p_F = 0 \Rightarrow \alpha F^{\alpha-1} E^{1-\alpha} = \lambda p_F$$
$$\frac{\partial L}{\partial E} = 0 \Rightarrow (1-\alpha) F^{\alpha} E^{-\alpha} - \lambda p_E = 0 \Rightarrow \left(1-\alpha\right) F^{\alpha} E^{-\alpha} = \lambda p_E \tag{11}$$

Solving the system of equations we find the marginal rate of substitution between food and ethanol. At the beginning we defined $p_E = 1$

$$\frac{\alpha F^{\alpha-1} E^{1-\alpha}}{\left(1-\alpha\right) F^{\alpha} E^{-\alpha}} = \frac{p_F}{p_E}$$
$$\frac{\alpha}{\left(1-\alpha\right)} \cdot \frac{E}{F} = p_F$$
$$E = p_F \frac{(1-\alpha)}{\alpha} F$$
$$F = \frac{1}{p_F} \frac{(1-\alpha)}{\alpha} E \tag{12}$$

The demand can be defined plugging equation (12) into the budget constraint

$$E = \frac{b}{2} \cdot \frac{\left(1-\alpha\right)}{\alpha} \tag{13}$$

Equation (13) suggests that ethanol demand depends solely on the consumer's income and on ethanol prices. However, the income is exogenous in this model and the price of ethanol was set to be equal to 1, therefore, when we take the total differential of equation (13) we find that ethanol demand in this model is fixed. In other words, it does not depend on any of the factors included in the model.

$$dE = 0 \tag{14}$$

Combining the supply and the demand sides of the problem by substituting (14) into equation (8), i.e. equalizing demand and supply, we find

$$dp_F = \left[\frac{L_E^{\delta-1}}{\gamma(L_T - L_E)^{\gamma-1}} - \frac{p_F(\gamma-1)L_E}{\delta A(L_T - L_E)} \right] dA - \frac{p_F(\gamma-1)}{L_T - L_E} dL_T \qquad (15)$$

This equation shows the relationship between food prices, ethanol productivity and total land used to produce both food and ethanol. However, it can be further simplified, given that equation (5) is $p_F = \frac{\delta A L_E^{\delta-1}}{\gamma(L_T - L_E)^{\gamma-1}}$. We finally get

$$dp_F = \frac{p_F}{\delta A} \cdot \frac{L_T - \gamma L_E}{(L_T - L_E)} dA - \frac{p_F(\gamma-1)}{L_T - L_E} dL_T \qquad (16)$$

3.3 Conclusion

The first term in the right hand side $\frac{p_F}{\delta A} \cdot \frac{L_T - \gamma L_E}{(L_T - L_E)}$ will always be positive, which implies that an increase in ethanol productivity will have a positive impact on food prices. This result is related to the fact that ethanol demand is fixed. According to equation (6), increases in land productivity are followed by increases in the amount of land allocated to produce ethanol, raising ethanol supply. As the demand for ethanol is fixed, the higher supply will lead to lower ethanol prices. Ethanol prices were defined as the numeraire, therefore, when referring to food prices, we are talking about food prices relative to ethanol prices, and when ethanol prices decrease, the relative price of food, with respect to ethanol, increases.

The second term $-\frac{p_F(\gamma - 1)}{L_T - L_E}$ also implies a positive relationship between total land and price of food. The rationale here is similar to the previous one. With more land available for cultivation, there will be also a larger share of land allocated for ethanol production, as defined in equation (6). Because the demand for ethanol is fixed, the increase in supply will be followed by lower ethanol prices. Again, food prices, relative to ethanol prices will increase.

CHAPTER 4

FOOD PRICES AND ETHANOL:

AN EMPIRICAL MODEL

The purpose of this chapter is to present the empirical analysis of the relationship between land allocated to ethanol production and world food prices; more specifically, whether sugarcane based ethanol and corn based ethanol production have similar impacts on food prices. It also examines how ethanol productivity relates to food prices.

4.1 The Data

The time series data required to empirically test the research hypothesis was obtained from the following sources: Brazilian Ministry of Agriculture (MAPA), Brazilian Institute of Geography and Statistics (IBGE), Brazilian Sugarcane Industry Association (UNICA), Attache Reports of USDA's Foreign Agriculture Service, US Energy Information Association (EIA), Renewable Fuels Association (RFA), International Monetary Fund (IMF), and the Food and Agriculture Organization of the United Nations (FAO).

Table 4 – Variable description

Variable	Definition
BRMktShare	Brazil share of total Ethanol produced in US and Brazil $\left(\frac{BR}{BR+US}\right)$
CaneEthArea	Planted area of cane used to produce ethanol in million acres
CornEthArea	Planted area of corn used to produce ethanol in million acres
LagCaneEthArea	$Lag_{(1)}$ of the variable CaneEthArea
LagCornEthArea	$Lag_{(1)}$ of the variable CornEthArea
CaneEthArea(%)	Proportion of cane area used for ethanol with respect to total planted cane area
CornEthArea(%)	Proportion of corn area used for ethanol with respect to total planted corn area
ExcRate	Real effective dollar exchange rate indices (based on relative consumer prices)
CHFood	China imports of food and live animals used for food (million US dollars)
OilPrice	Real crude oil price per barrel (yearly average)
LagOil	$Lag_{(1)}$ of the variable OilPrice
pF/pE	Relative food price – Ratio between food price index and ethanol price index
Lag_pF/pE	$Lag_{(1)}$ of the variable pF/pE
Food/CPI	Relative food price – Ratio between food price index and consumer price index

In Figure 2, we show the key variables used in the model, indicating the directionality of the relationship. The dataset consists of annual data ranging from 1980 to 2007, and this empirical evaluation is performed using regression analysis. Appendix 1 has a table with the summary statistics for all the variables included in the model.

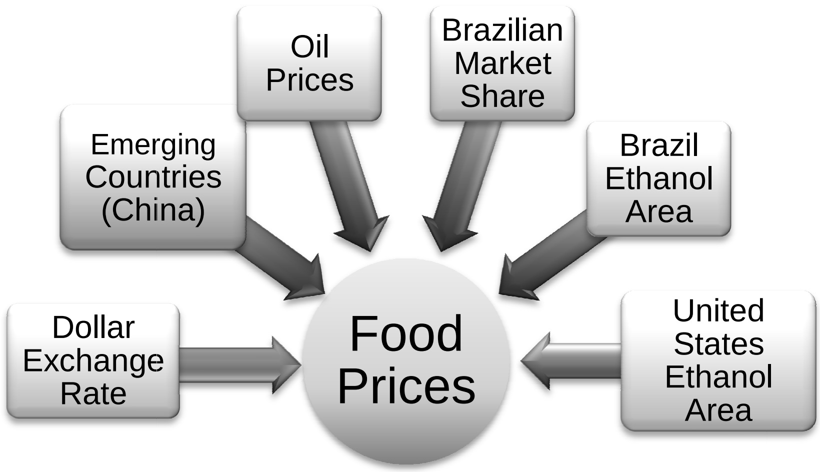

Figure 2 - Variables in the Empirical Model

Dependent Variables – Relative Food Prices

Two sets of dependent variables are tested separately, and in accordance with the theory in chapter 3, both represent relative food prices. Most price indexes used in this thesis were obtained from the International Financial Statistics (IFS – October 2008) dataset, organized by the International Monetary Fund (IMF). These indices were compiled by the IMF as period averages in terms of U.S. dollars and expressed using a 2000=100 weights reference period. They are expressed in terms of a base year value of 100 (2000) and all changes are expressed as a percentage changes from that base.

The commodity food price index, which is part of our dependent variable, includes weighted cereal, vegetable oils, meat, seafood, sugar, bananas, and oranges price indices. The weights given to sugar (1.9 percent) and corn (1.7 percent) are similar, justifying the adoption of this index. As both, corn used for food and sugar, compete directly with ethanol, it is desirable that the proxy for overall food inflation give the same weight to both commodities.

It would be preferable to have at least quarterly data on food prices, because, as suggested by R. McFall Lamm and Paul C. Westcott (1981), increases in input prices pass quickly to consumers in the food sector, within two quarters for most food products. Hence, having quarterly data for food prices and the remaining variables would allow to better capture the variability in food prices.

In Figure 3 we compare the food prices index with the price indices for corn and sugar. The corn index is based on US corn and the sugar index based on Brazilian export prices for sugar. It is important to look into the prices of these two commodities because they are the ones primarily linked with the ethanol market, given that they may compete directly with ethanol production.[25] Of course, it is also possible that land be diverted from a food crop (e.g., wheat) to an ethanol crop (e.g., corn).

The corn prices adopted in the index are based on the average of daily quotations of the US Gulf Ports f.o.b. prices. Sugar prices, differently, are based in three different estimates, EU import price, which

[25] About the relationship between sugar and ethanol, see Elobeid and Tokgoz (2006).

is the negotiated export price for sugar from ACP countries[26] to EU, Sugar Free Market (CSCE[27] contract no.11), and U.S. sugar import price CSCE contract no.14. To build the chart, we averaged the three sugar price indices. Observing Figure 3, one will notice that the increase in the food prices index during 2005 and 2006 was followed by a raise in both corn and sugar prices. However, during 2007, sugar prices declined, whereas corn prices kept on a steep, upward trend in prices, followed by the food index. The decline in sugar prices during that period is partly due to a surplus in the world sugar production.[28]

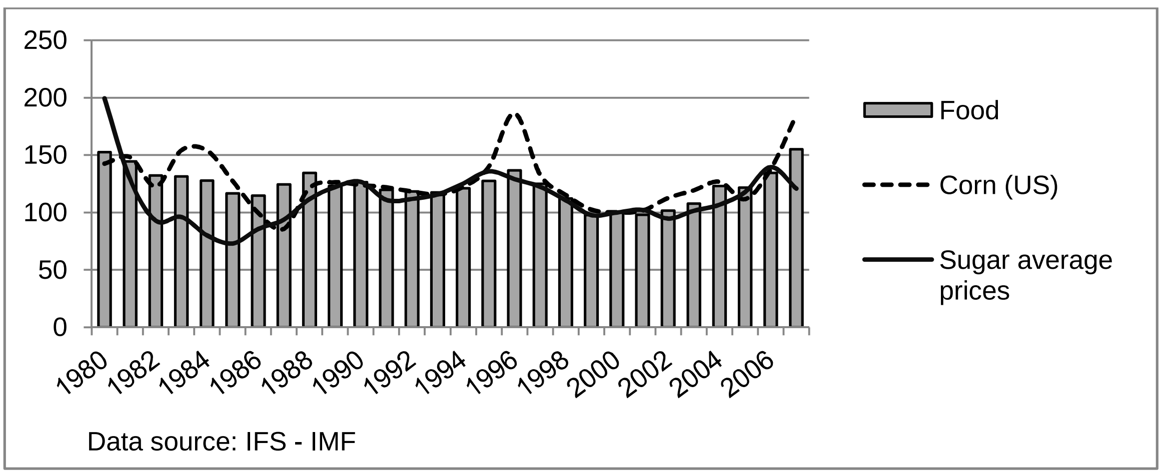

Figure 3 - Commodities Price Index

In the empirical test, we will consider two dependent variables representing relative food prices. The first one uses the food price index relative to the World Consumer Prices Index (CPI) compiled by the IMF

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[26] African, Caribbean and Pacific (ACP) group of countries, created by the Georgetown Agreement in 1975 with the purpose of promoting development for the group. It involved the Lome Convention, a trade and aid agreement between European Union Countries and the ACP countries.
[27] Coffee Sugar and Cocoa Exchange (CSCE) contract on nearest future position.
[28] UNICA at www.unica.com.br. Accessed in 03/10/09.

(IFS – October 2008) and the second one uses the ratio between the food price index and an ethanol prices index built by the author using data obtained from the Brazilian Ministry of Agriculture.

Figure 4 shows how each of these price indices varied over time. The food price index was relatively stable between 1986 and 1996, when it suffered a sharp decline that lasted until early 2000, and since it has increased consistently. Ethanol prices presented up and down oscillations throughout the whole period, and finally the World CPI shows an upward trend.

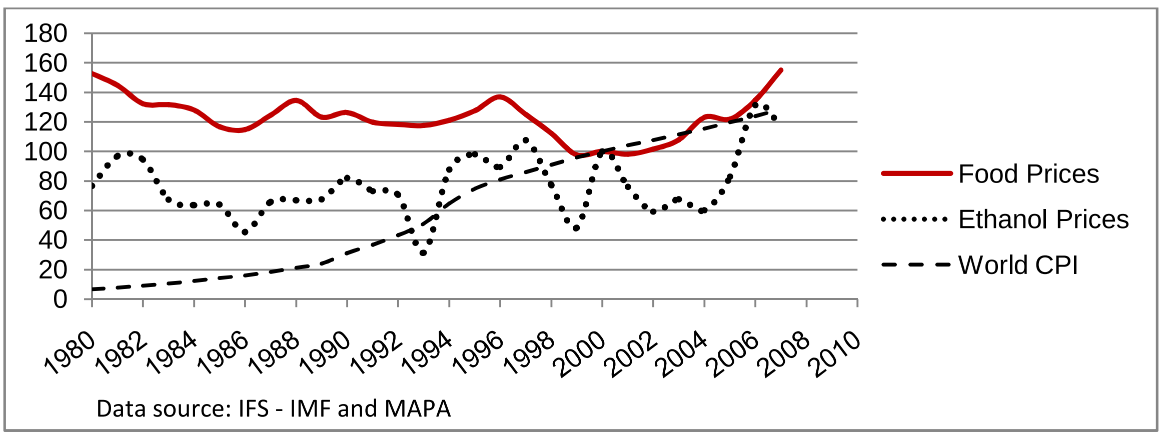

Figure 4 - Key Price Indexes

Ratio between Food Prices and CPI $\left(\frac{p_F}{CPI}\right)$

CPI is one of the most frequently used indicators of inflation and reflects changes in the cost of acquiring a fixed basket of goods and services by the average consumer. When we divide the food price index by the World CPI, we get a deflated estimator. This ratio is represented in Figure 5.

According to the IMF description of the data, this index is compiled giving preference to series having wider geographical coverage and relating to all income groups, provided they are as current as more narrowly defined series.

Ratio between Food Prices and Ethanol Prices $\left(\frac{p_F}{p_E}\right)$

Ethanol prices are Brazilian anhydrous ethanol export prices.[29] Part of the data was available only in the Brazilian currency, and was converted to the corresponding US dollar value. Finally, the data was indexed to the year 2000 to stay consistent with the IMF data. The dependent variable represented by the ratio between food and ethanol prices, shown in Figure 5, was included in the empirical model to test the theory developed in Chapter 3, in which food prices were defined relatively to ethanol prices.

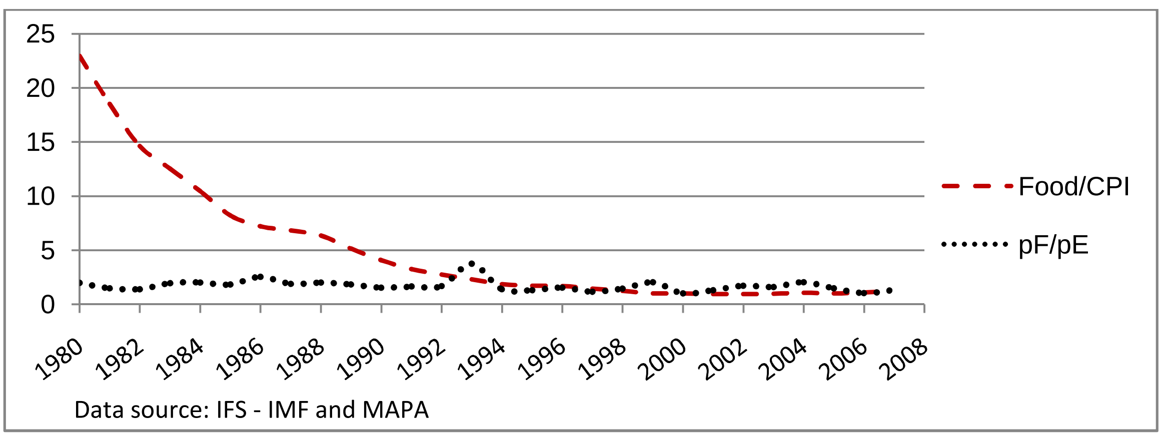

Figure 5 - Dependent Variables

[29] Elobeid and Tokgoz (2006) also used Brazilian ethanol prices as a proxy for international ethanol prices.

Independent Variables

The independent variables can be divided in two groups; the first one contains key variables, which will allow testing the research hypothesis. The second group contains the control independent variables and is based on the food inflation factors identified in the survey of the existing literature. As part of the second group, we have the variables Dollar Exchange Rate, China Imports and Oil Prices. The remaining variables are part of the first group.

Brazilian Market Share of Ethanol Production

The Brazilian market share of ethanol production was calculated using the ratio between Brazilian ethanol production and total ethanol produced by Brazil and the US together. Data for ethanol production in Brazil was obtained from two sources, IBGE and UNICA, and is given in millions of liters. US data is from the RFA and is also given in million liters.

The theoretical model found that higher ethanol productivity is to be followed by higher food prices (relative to ethanol prices), and we intend to empirically test this relationship using ethanol market share as a proxy for ethanol productivity.[30] Observing Figure 6 we see how the US rapidly expanded its ethanol production from 24 percent in 1997 to 52 percent of the market share in 2007. Brazil and the US together occupy over 70 percent of the world ethanol production. Moreover, production

[30] The use of market share as a proxy for productivity can also be found on Sajal Lahiri and Yoshiyasu Ono (2004).

figures are more reliable for these two countries. According to Walter et al, there are inconsistencies in the data regarding total world production prior to 2000, caused, among other factors, by the different uses of ethanol and unreliability of statistic information; hence, we limit our analysis to Brazil and the US. Comparing Figure 6 and Figure 9 we see that for year 2007, the US used twice as much land as Brazil to produce approximately the same amount of ethanol. This suggests that Brazilian ethanol productivity is still considerably higher than that of the US.

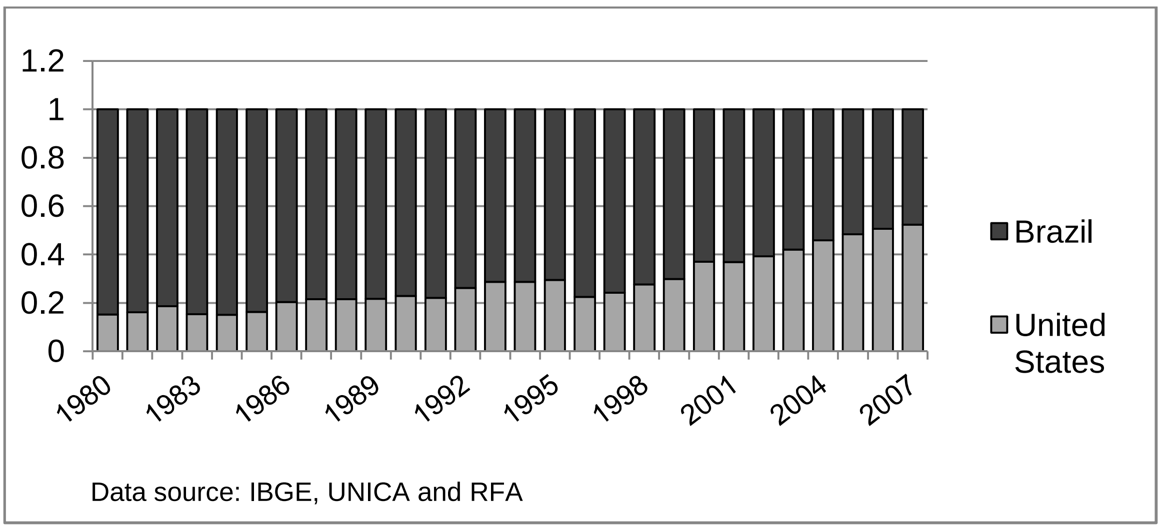

Figure 6 - Ethanol Market Share

The following charts show the total production of the two main ethanol crops, sugarcane and corn, in Brazil and the US, respectively. These charts include the proportion of the total production that is allocated to produce ethanol. Brazil has been producing ethanol in large scale since the 1970s, after the first oil shock[31], and Figure 7 shows that

[31] Walter et al. (2007).

a large proportion of the sugarcane produced in that country is used to produce ethanol, with over 50 percent of total sugarcane production being allocated to ethanol production in year 2008.[32] Differently, in the US, ethanol production was very small until a decade ago, and when compared to the total corn production, it corresponds to a much smaller fraction of the total production than that observed for Brazil. In 2008, when ethanol production in the US reached the highest value in the series, it corresponded to about a third of the total corn produced in that year.

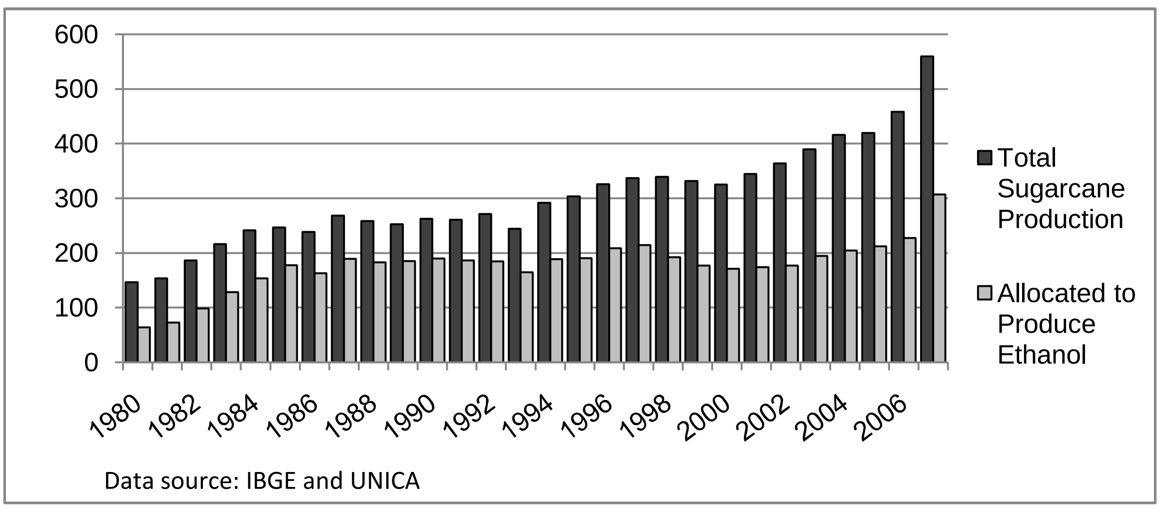

Figure 7 - Brazil Sugarcane Production (in million tons)

[32] It is interesting to point out that Brazilian sugarcane production has two major destinations: ethanol and sugar. Hence, it is safe to assume that the remaining 50 percent of sugarcane is allocated to produce sugar.

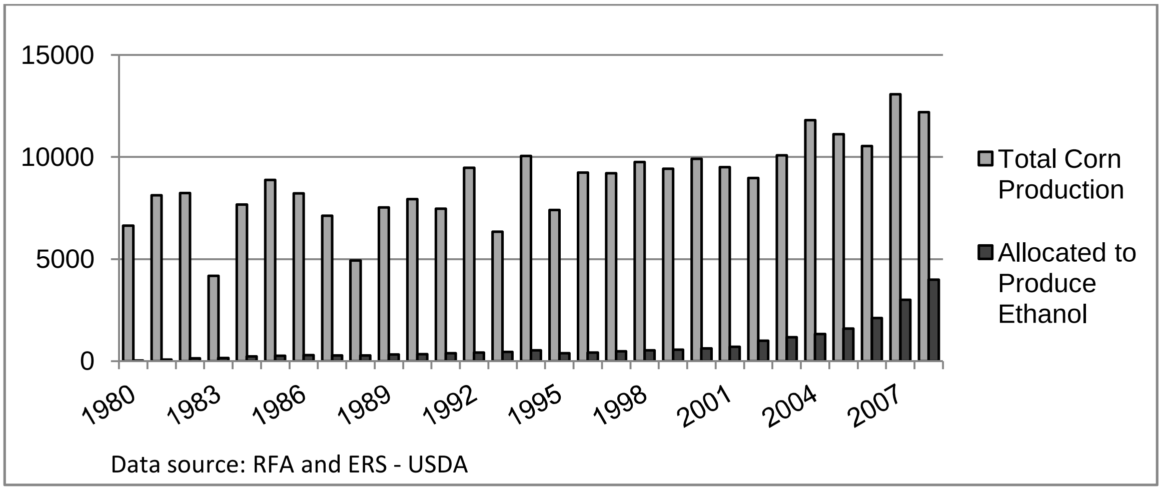

Figure 8 - US Corn Production (in million bushels)

Sugarcane Area

The Brazilian Ministry of Agriculture (MAPA) and the Brazilian Institute of Geography and Statistics (IBGE) supplied the data on sugarcane planted area, and area allocated to produce ethanol.

Area Allocated to Ethanol Production – this variable accounts for the diversion of land from food production to ethanol production.

Lag of Sugarcane Area Allocated to Ethanol Production – the lag of the sugarcane area was included to account for a possible delay in the price response to land allocation. In other words, it intends to account for the possibility that this year's food prices were influenced by the amount of land allocated to produce ethanol last year.

Proportion of Total Sugarcane Area Used to Produce Ethanol – allocating more land to ethanol production can affect food prices in two ways, reallocating food crops to fuel production or diverting agricultural land from food crops to energy crops. This variable consists in the ratio between sugarcane area allocated to ethanol production divided by total sugarcane area, and it will capture the effect of reallocating a food crop to produce fuel, without necessarily expanding the total sugarcane area planted.

Corn Area

The Economic Research Service of the US Department of Agriculture (ERS-USDA) compiled the data on corn planted area and area allocated to produce ethanol. We collected similar data for sugarcane based ethanol and corn based ethanol because we are interested in comparing the impact of both sources of ethanol on food prices. The next two charts present the total planted area for both crops and the correspondent area allocated for ethanol, comparing Brazil and the US. The total land allocated to both crops (Figure 10) did oscillate over the period under consideration, but not as much as the area allocated for ethanol production. Figure 9 shows how the Brazilian ethanol area varied little between 1985 and 2005, and has increased since. In the case of the United States, it was only in the year 2000 that the area allocated to ethanol overcame 5 million acres, and in less than 8 years reached 20 million acres, four times more.

Area Allocated to Ethanol Production – this variable accounts for the diversion of land from food production to ethanol production and we are interested in comparing the coefficients of the corresponding variables corn area and sugarcane area.

Lag of Corn Area Allocated to Ethanol Production – similarly to the sugarcane area, the area allocated to corn ethanol at the previous period was included to account for a possible delay in food price response to land allocation.

Proportion of Total Corn Area Used to Produce Ethanol – this variable was calculated in the same way and with the same purpose of its correspondent sugarcane ethanol. However, it is important to highlight that corn has several uses in the food and feedstock industry; hence, it is difficult to determine, without further investigation, which of those are more affected when a higher share of corn production is allocated to produce ethanol.

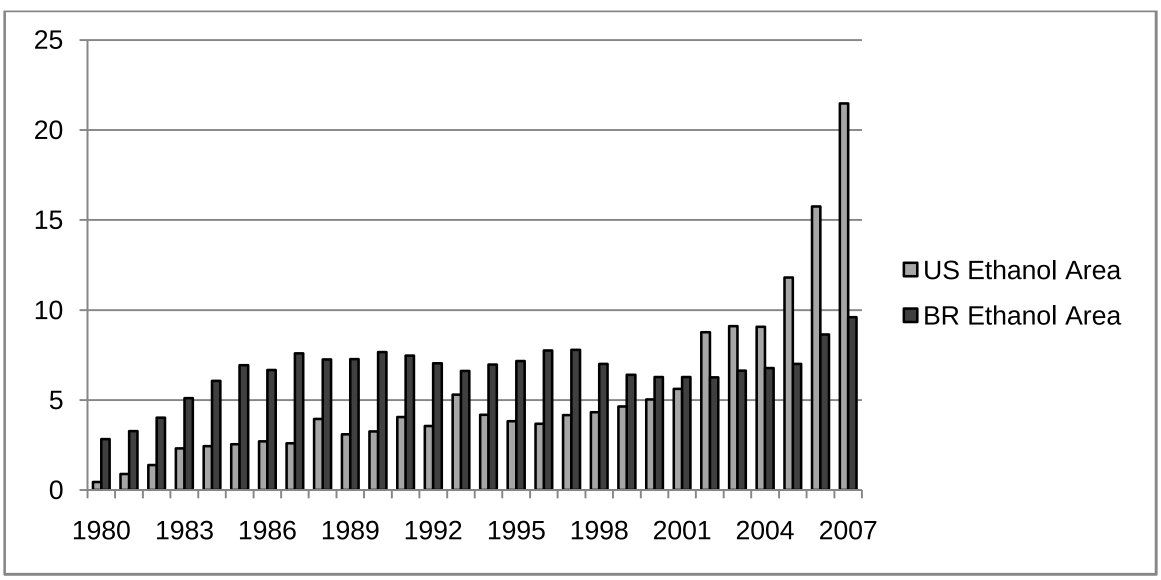

Figure 9- Ethanol Areas (in million acres)

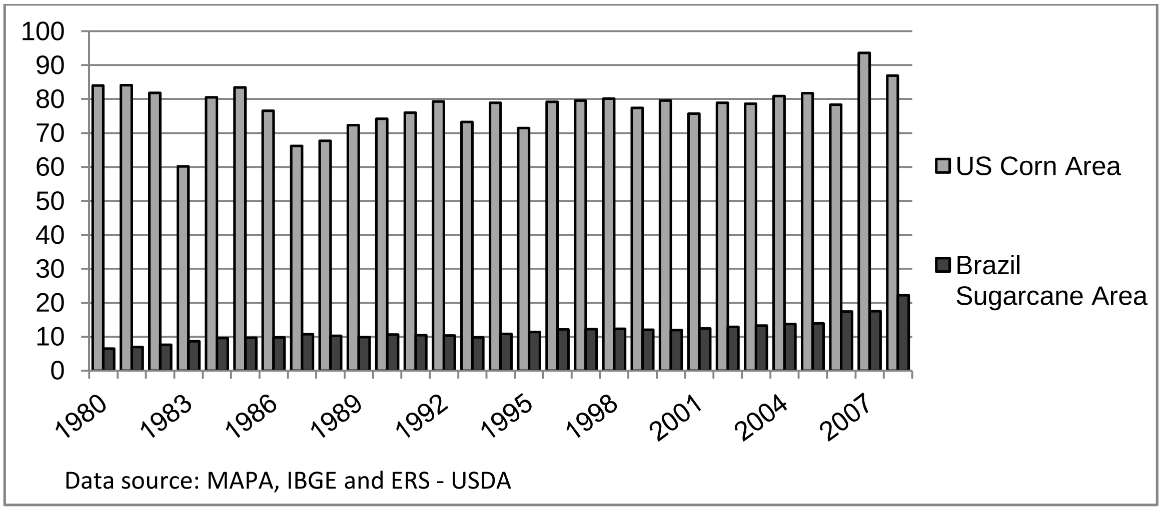

Figure 10 - Sugarcane and Corn Areas (in million acres)

Dollar Exchange Rate

This variable intends to capture the impact of the dollar exchange rate on world food prices, given that most world commodities are traded in dollar. Currency depreciation affects the relative prices of tradable and non-tradable goods. Consequently, a depreciation of the dollar is likely to be followed by higher food inflation. To capture this effect, we use the IFS real effective exchange rate based on relative consumer prices. According to the IMF description, the real effective exchange rate index is derived from the nominal effective exchange rate index,[33] adjusted for relative changes in consumer prices. Consumer price indices, often available monthly, are used as a measure of domestic costs and prices. In other words, this index considers the dollar valuation with respect to a number

[33] A nominal effective exchange rate index represents the ratio (expressed on the base 2000=100) of an index of a currency's period average exchange rate to a weighted geometric average of exchange rates for the currencies of selected countries and the euro area (International Financial Statistics - World and Country Notes, October 2008).

of other currencies. An increase in the index reflects an appreciation of the dollar.

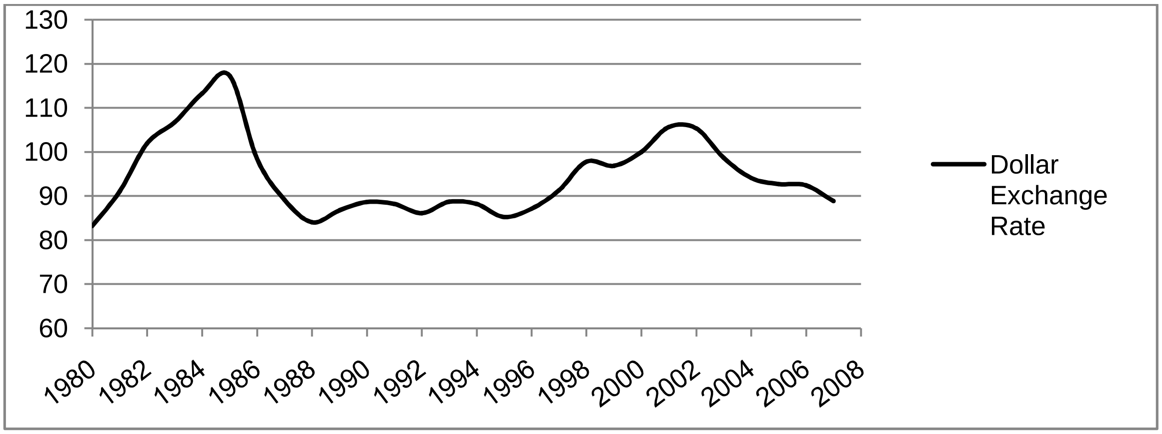

Figure 11 - Dollar Exchange Rate

China Imports of Food

The ERS-USDA compiled this data, which intends to capture the effect that higher demand from developing countries had on overall food prices. The literature suggests that the accelerated growth of developing countries, especially China, led to a considerable increase in the consumption and quantity imported of meat and dairy products. That is the reason why we chose to use China imports of food and live animals used for food as a proxy for the increased demand from developing countries. The data is in millions of US dollars.

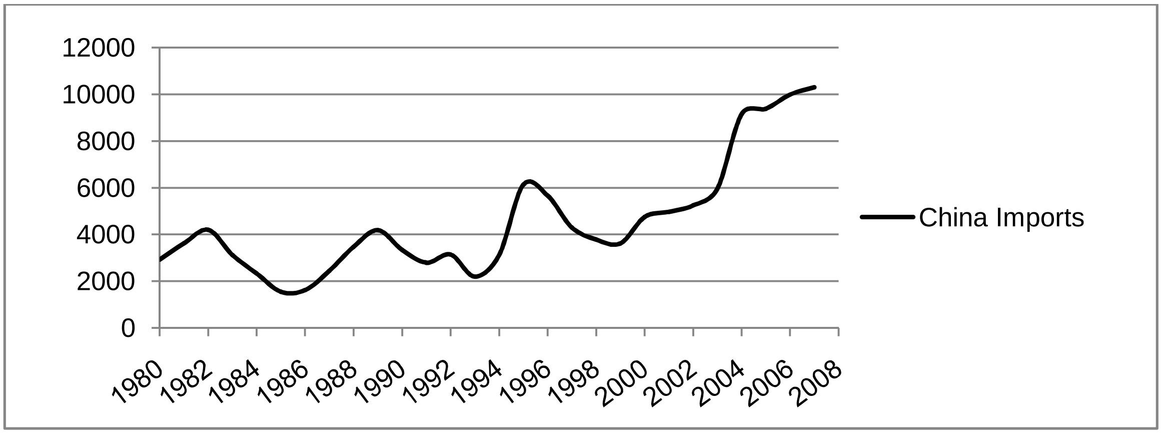

Figure 12 - China Imports of Food

Oil Prices and Lagged Oil Prices

Monthly data on real imported crude oil prices (barrel per dollar) is available at the Energy Information Association (EIA) database. We use the yearly average of the referred data. Oil prices may be playing an important role in the recent surge on ethanol production, given that oil prices need to be beyond a certain level to create economic incentives to invest on ethanol. Besides this possible relationship between oil prices and ethanol, the observed increase in oil prices after 2002 until mid 2008 (see Figure 13) is may have affected food prices, due to its importance in food production and transportation. We chose to use oil prices, rather than its sub products, because we believe the later will follow the oscillations on real crude oil prices. We also included a lagged oil prices variable to account for a delay in food price responses to higher energy costs.

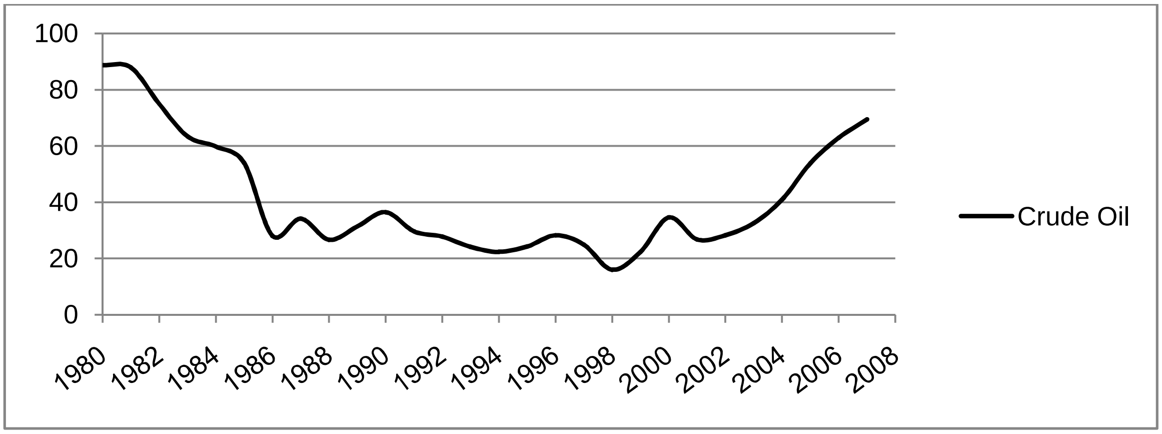

Figure 13 - Oil Prices

Lag of the Dependent Variable $\left(\frac{p_F}{p_E}\right)_{t-1}$

Finally, the lag of the dependent variable food prices relative to ethanol prices was included in the second set of regressions. This variable is intended to capture the impact of past inflation on future prices. The inclusion of this variable will be further discussed later in this chapter.

4.2 Testing for stationarity

Before investigating how these sets of variables affect food prices it is necessary to establish the properties of the individual variables. The Box-Jenkins approach is a widely accepted methodology for the analysis of time series data and is used here as a starting point. As described by G.S. Maddala (1992), the Box-Jenkins methodology follows five steps, as schematically demonstrated in Figure 14.

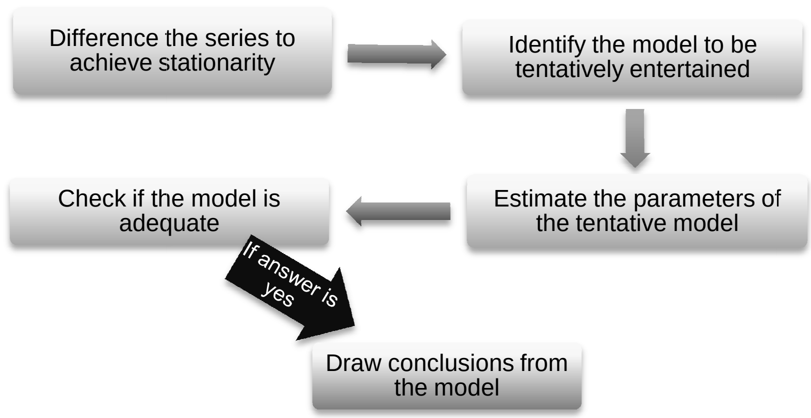

Figure 14 - Adaptation of the Box-Jenkins Methodology

Having a stationary time series is important in economic modeling because it prevents the occurrence of spurious regressions, commonly found in the economic literature.[34] A weakly stationary time series has mean, variance and autocorrelation constant over time. If that is not the case, one has a nonstationary time series, which may produce misleading regression results. Furthermore, the R^2 of a nonstationary series tends to a random variable (many times suggesting a very high relationship), rather than to zero.[35]

A large number of economic time series are nonstationary; hence the first step will be to perform a stationarity test. The Dickey-Fuller (DF) and augmented Dickey-Fuller (ADF) test statistics are used to determine

[34] See C. W. J. Granger and Paul Newbold (1986) and R. F. Engle and C. W. J. Granger (1987).
[35] Damodar N. Gujarati (2004) and Jeffrey M. Wooldridge (2002).

if the series are stationary. The DF test equation for unit root[36] is estimated in three different forms, depending on the nature of the random walk process (no drift – or intercept, with drift or with drift and a time trend):

$$\Delta Yt = \delta Y_{t-1} + u_t$$
$$\Delta Yt = \beta_1 + \delta Y_{t-1} + u_t$$
$$\Delta Yt = \beta_1 + \beta_2 t + \delta Y_{t-1} + u_t$$

For all cases the null hypothesis is $\delta = 0$, or that there is a unit root (series is nonstationary). The alternative is that $\delta < 0$, indicating the time series is stationary. The ADF test is conducted by augmenting the three equations above with lagged values of the dependent variable ΔY_t. Y_t is any of the series to be tested (e.g., CaneEthArea, ExcRate or OilPrice). The number of lags is determined empirically by adding enough lags so that the error term is serially uncorrelated. The ADF test consists in estimating the following equation:

$$\Delta Yt = \beta_1 + \beta_2 t + \delta Y_{t-1} + \alpha_i \sum_{i=1}^{n} \Delta Y_{t-1} + \varepsilon_t$$

where $\sum_{i=1}^{n} \Delta Y_{t-1}$ is the number of lag terms included. In this thesis, the unit root test was estimated in the three different forms with up to 2 lagged difference terms. The decision on the proper specification of the DF and ADF equations was based on the Akaike information criterion (AIC) and the Schwarz criterion or Bayesian information criterion (BIC). The

[36] The name comes from the fact that ρ=1 in the autoregressive process of order one model.

equations with the minimum values of the Akaike test and BIC were chosen as the best structure of the DF/ADF test.

The results of the unit root tests, shown in Table 5, indicate that some of the series are nonstationary. Differencing the series once was enough to achieve stationarity, suggesting the nonstationary variables were /(I) (integrated of order 1).

Table 5 **- DF and ADF unit root tests**

Variables	Variables in Levels		Variables in 1st Differences	
BRMktShare*	0.828 [2, c]	Nonstationary	-5.167 [0, c, t] (0.0001)	Stationary
CaneEthArea	-2.214 [1, c] (0.0185)	Stationary	-2.651 [0] (p-value < 0.02)	Stationary
CornEthArea*	3.207 [2, c]	Nonstationary	-1.580 [0, c] (0.0635)	Stationary
LagCaneEthArea	-2.613 [1, c] (0.0079)	Stationary	-2.320 [0] (p-value < 0.05)	Stationary
LagCornEthArea*	3.166 [2]	Nonstationary	-3.860 [0, c, t] (0.0138)	Stationary
CaneEthArea(%)*	-2.985 [0, c, t]	Nonstationary	-3.437 [0] (p-value<0.001)	Stationary
CornEthArea(%)	-3.097 [1, c] (0.0025)	Stationary	-4.905 [0, c, t] (0.0003)	Stationary
ExcRate	-2.561 [2, c] (0.0091)	Stationary	-3.032 [2] (p-value<0.001)	Stationary
CHFood*	-1.798 [2, c, t]	Nonstationary	-3.668 [2, c, t] (0.0245)	Stationary
OilPrice*	-0.496 [2, c, t]	Nonstationary	-3.394 [2, c, t] (0.0522)	Stationary
LagOil*	-0.607 [2, c, t]	Nonstationary	-3.231 [2, c, t] (0.0783)	Stationary
pF/pE	-4.727 [0, c] (0.0000)	Stationary	-6.183 [1] (p-value<0.001)	Stationary
Lag_pF/pE	-3.354 [2, c, t] (0.0579)	Stationary	-5.940 [1] (p-value<0.001)	Stationary
Food/CPI	-4.650 [2, c] (0.0001)	Stationary	-4.289 [2] (p-value<0.001)	Stationary

(nonstationary variables are marked with *)
In brackets are indicators of number of lagged terms, inclusion of an intercept (c) and the inclusion of a trend (t).
Approximate p-values are given inside parentheses for the stationary variables. The statistical package used (STATA) provides MacKinnon approximate p-values for the DF and ADF test statistics.

4.3 The Regressions

The empirical model captures the effects of monetary and macroeconomic factors on relative food prices. Two sets of regressions using two different dependent variables were developed. In the first group, the effect on the ratio between food prices and CPI $\left(\frac{p_F}{CPI}\right)$ was investigated, followed by another set of four regressions examining the impact on the dependent variable ratio of food prices and ethanol prices $\left(\frac{p_F}{p_E}\right)$. The second dependent variable intends to test the theoretical model, in which we have the ratio between food prices and ethanol prices.

For each dependent variable, the four sets of regressions are first estimated without the intercept term (Table 6 and Table 8). The intercept was not included in these models, because first differencing the data, nullifies the constant. According to Gujarati (2004), an interesting feature of the first-difference model is that there is no intercept in it. This author suggests the regression through the origin routine should be used. However, we also decided to estimate the regressions including the intercept (Table 7 and Table 9), to compare the results. The significant coefficients for each regression are described along with its corresponding table.

Table 6 – Regression estimates without intercept. Dependent variable: $\frac{p_F}{CPI}$

Variables	Regression 1	Regression 2	Regression 3	Regression 4
BRMktShare	15.506 (0.050)**	8.649 (0.213)	10.855 (0.092)***	15.175 (0.043)**
CaneEthArea	-1.196 (0.002)*	—	—	—
CornEthArea	0.105 (0.444)	—	—	—
LagCaneEthArea	—	-0.581 (0.109)***	-1.049 (0.002)*	—
LagCornEthArea	—	-0.073 (0.652)	0.017 (0.905)	—
CaneEthArea(%)	—	—	—	-21.406 (0.001)
CornEthArea(%)	—	—	—	-1.386 (0.892)
ExcRate	-0.107 (0.004)*	-0.093 (0.010)*	-0.102 (0.003)*	-0.094 (0.008)*
CHFood	-0.171 (0.405)	-0.124 (0.520)	-0.044 (0.792)	-0.283 (0.145)
OilPrice	0.086 (0.001)*	0.058 (0.025)**	—	0.083 (0.001)*
LagOil	—	—	0.063 (0.004)*	—
Adj_R^2	0.564	0.403	0.494	0.603
F- statistics	6.828*	3.921*	5.228*	7.824*
Durbin Watson[37]	1.389 (df=27)	1.230 (df=26)	1.381 (df=26)	1.347 (df=27)

(*, **, *** : indicates the coefficient is significant at 1, 5 or 10 percent level, respectively.)
DW critical values: df=26, k=6 independ. variables: d_L=0.897, d_U=1.992. df=27, k= 6: d_L=0.925, d_U=1.974.

In Regression 1 (Table 6), four out of six variables turned out significant. Relative food prices rose with increases in the Brazilian ethanol market share *(BRMktShare)*. An increase in *BRMktShare* is associated with a raise in the relative world food prices index. This variable intends to capture the productivity factor from the theoretical

[37] The Durbin-Watson test was used to check if serial correlation was present in the regressions. According to the D-W critical values, one cannot say that there is autocorrelation in any of the regressions under consideration.

model and this result is consistent to what we found in the theoretical framework.

Contrary to *a priori* expectations, increases in area allocated to produce ethanol in Brazil (CaneEthArea) had depressing effects on relative food prices. The coefficient on this variable indicates that, an increase of 1 million acres in the area planted of cane used to produce ethanol is associated with a decrease in the relative world food prices index of 1.19. One would expect that producing more ethanol, given that ethanol and sugar (food) compete for land, would decrease supply of food and raise its price. That was not the case here and to understand this result we need to look at the correlations between ethanol area, sugar area, and total sugarcane area. As we said before, sugarcane crops in Brazil are allocated, mainly, to ethanol and sugar. The pearson correlation (r) between ethanol and sugarcane is 0.767, which suggests these variables are positively and strongly correlated. The same is true for the relationship between sugarcane and sugar (r = 0.848). Therefore, what might be happening with the regression coefficient is that the negative relationship between ethanol area and the food index is due to the fact that the area of cane, and consequently sugar, has historically increased together with the ethanol area. If sugar area is increasing, the supply of sugar increases, exerting downward pressure on sugar prices, and thus, food prices. We further conclude that the negative impact of the higher sugar production is overpowering a possible positive impact the ethanol area would have on food prices.

Currency depreciations are generally followed by higher overall prices. Accordingly, a decrease of 1 unit in the dollar exchange rate (ExcRate), in Regression 1, is associated with an increase in the relative world food prices index of 0.107. The impact of oil prices (OilPrices) were as expected. Ceteris paribus, an increase of 1 dollar in the barrel of crude oil is associated with an increase in the relative world food prices index of 0.086. The effects of China food imports on relative food prices are inconclusive, because the coefficient for CHFood is not statistically significant. All regressions on Table 3 present the same result for the CHFood variable.[38]

In Regression 2 (Table 6), we substitute the area variables by the corresponding first lag. In this new regression, the variable BRMktShare was no longer significant. The remaining key variables in this regression are the lagged cane areas. The coefficient of Corn Ethanol Area (LagCornEthArea) was not significant; hence, the effects of past corn areas allocated to produce ethanol in the US cannot be determined. With respect to the effects of past corn ethanol area (LagCaneEthArea) on relative food prices, the coefficient indicates that, ceteris paribus, an increase of 1 million acres in the area planted of cane, in the previous period, is associated with a decrease in the relative world food prices

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[38] The adjusted R^2 suggests that 56.4% of the variability in relative food prices is explained by Regression1.

index of 0.58. This is a surprising outcome, and suggests that more area allocated to ethanol production in Brazil, is likely to lead to a reduction on future food prices. The rationale here is similar to what we described in Regression 1 with respect to the CaneEthArea coefficient. The negative relationship between the lag of ethanol area and the food index results from the fact that the area of sugarcane, historically, has varied together with the ethanol area. Similarly, sugar area and sugarcane area, have also varied together. Therefore, an increase in ethanol area follows an increase in the total sugarcane area, and so does the sugar area. If sugar area is increasing, the supply of sugar increases, exerting downward pressure on next year's sugar prices, and thus, food prices.

The effects of ExcRate and OilPrice on relative food prices were as expected. A decrease of 1 unit in the dollar exchange rate is associated with an increase in the relative world food prices index of 0.09, while an increase of 1 dollar in the barrel of crude oil is associated with an increase in that index of 0.058.[39]

Regression 3 (Table 6) differs from Regression 2 for using the lagged oil price (OilPrice). BRMktShare is statistically significant and positively associated with the relative food prices index. LagCornEthArea is not significant and the LagCaneEthArea coefficient suggests that for every additional million acres in cane planted area, in the previous period, the food price index should be expected to decrease by 1.049. No

[39] The adjusted R^2 suggests that 40.3% of the variation in relative food prices is explained by Regression2.

surprises with the effects of ExcRate and OilPrice on relative food prices. The relative food price index is expected to increase 0.102 with a one point decrease in the dollar exchange rate, whereas an increase of 1 dollar in the barrel of crude oil, in the previous period, is associated with an increase in the relative world food prices index of 0.063. [40]

The key area variables in Regression 4 (Table 6) are the percent variation in the amount of area allocated to ethanol production (CaneEthArea% and CornEthArea%), however neither one of these key area variables were statistically significant. The result for remaining variables was similar to the previous regressions, indicating that an increase of 1% in the Brazilian Market Share of ethanol is associated with an increase in the relative world food prices index of 15.17. A depreciation of 1 point in the dollar exchange rate is associated with a raise of 0.094 point in the food prices index. Finally, the impact of higher oil prices is associated with a marginal increase of 0.083 in the index for food prices. [41]

In Table 7, the intercept was included in all regressions from Table 6, in order to see if significant changes would occur. The intercept term was significant in all regressions and it seems to be capturing the effect from some of the key independent variables. For example, the variable BRMktShare was no longer significant in Regressions 1, 3 and 4. The

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[40] The adjusted R^2 suggests that 49.4% of the variation in relative food prices is explained by Regression 3.
[41] 60.3% of the variability in relative food prices is explained by Regression 4, according with the adjusted R^2.

variable LagCaneEthArea in Regression 2 also became insignificant after the inclusion of the intercept. The regressions on Table 6 have a higher overall significance (F-test) and higher adjusted R^2, thus, suggesting the regression through origin is a better fit for the model with the ratio between food prices and CPI as the dependent variable.

Table 7 – Regression estimates with intercept. Dependent variable: $\frac{p_F}{CPI}$

Variables	Regression 1	Regression 2	Regression 3	Regression 4
Intercept	-0.498 (0.050)**	-0.546 (0.015)*	-0.433 (0.049)**	-0.595 (0.005)*
BRMktShare	8.571 (0.278)	1.556 (0.812)	5.024 (0.436)	7.861 (0.230)
CaneEthArea	-0.929 (0.014)*	—	—	—
CornEthArea	0.176 (0.189)	—	—	—
LagCaneEthArea	—	-0.340 (0.294)	-0.809 (0.011)*	—
LagCornEthArea	—	0.035 (0.813)	0.098 (0.479)	—
CaneEthArea(%)	—	—	—	-18.672 (0.001)*
CornEthArea(%)	—	—	—	-9.667 (0.306)
ExcRate	-0.096 (0.006)*	-0.078 (0.015)*	-0.087 (0.007)*	-0.080 (0.009)*
CHFood	-0.086 (0.659)	-0.052 (0.757)	0.013 (0.935)	-0.149 (0.372)
OilPrice	0.071 (0.005)*	0.052 (0.023)**	—	0.068 (0.002)*
LagOil	—	—	0.051 (0.013)*	—
Adj_R^2	0.465	0.342	0.376	0.600
F- statistics	4.760*	3.162**	3.508*	7.508*
Durbin Watson	1.186 (df=26)	1.161 (df=25)	1.254 (df=25)	1.295 (df=26)

(*, **, *** : indicates the coefficient is significant at 1, 5 or 10 percent level, respectively)
DW critical values: df=25, k=7 indep. variables: d_L=0.784, d_U=2.144. df=26, k= 7: d_L=0.816, d_U=2.177.

The Regressions in Table 8 were estimated to link this empirical investigation with the theoretical model presented in Chapter 3. The independent variables remain the same, but now we are interested in their impact on the ratio of food prices and ethanol prices $\left(\frac{p_F}{p_E}\right)$. The lag of the dependent was included in the regressions in order to reach overall significance in the model, because when regressed solely on the same independent variables used in Table 6, the F-statistic was not significant. Nonetheless, it seems that the lagged dependent variable is capturing most of the impact on relative prices, given that most independent variables are statistically insignificant.

Table 8 – Regression estimates without intercept. Dependent variable: $\frac{p_F}{p_E}$

Variables	Regression 1	Regression 2	Regression 3	Regression 4
Lag_pF/pE	-0.452 (0.038)**	-0.595 (0.014)**	-0.681 (0.007)*	-0.527 (0.026)**
BRMktShare	0.944 (0.860)	-3.459 (0.499)	-3.825 (0.441)	-2.162 (0.984)
CaneEthArea	-0.405 (0.104)***	—	—	—
CornEthArea	0.132 (0.193)	—	—	—
LagCaneEthArea	—	-0.110 (0.702)	-0.089 (0.734)	—
LagCornEthArea	—	-0.009 (0.947)	0.004 (0.977)	—
CaneEthArea(%)	—	—	—	0.083 (0.616)
CornEthArea(%)	—	—	—	4.244 (0.701)
ExcRate	-0.014 (0.564)	-0.026 (0.318)	-0.024 (0.345)	-0.023 (0.388)
CHFood	-0.217 (0.189)	-0.325 (0.051)**	-0.349 (0.025)**	-0.295 (0.088)***
OilPrice	-0.010 (0.536)	-0.007 (0.698)	—	-0.007 (0.681)
LagOil	—	—	-0.017 (0.310)	—
Adj_R^2	0.288	0.180	0.218	0.181
F- statistics	2.500***	1.815	2.036***	1.823
Durbin Watson	2.306 (df=26)	2.361 (df=26)	2.353 (df=26)	2.360 (df=26)

(*, **, *** : indicates the coefficient is significant at 1, 5 or 10 percent level, respectively)
DW critical values: df= 26, k= 7 indep. variables: d_L= 0.816, d_U= 2.177.

The key area variables in Regression 1 (Table 8) are the areas of cane and corn allocated to produce ethanol (CaneEthArea and CornEthArea). Increases in area allocated to produce ethanol in Brazil had depressing effects on relative food prices. The coefficient on this variable indicates that an increase of 1 million acres in the area planted of cane used to produce ethanol is associated with a decrease in the relative world food prices index of 0.405. The effect of the US corn area allocated to ethanol cannot be determined because the coefficient for CornEthArea is statistically insignificant.

Past food prices, represented by the variable Lag_pF/pE, have negative effects on current food prices. The coefficient suggests that a marginal decrease in relative food prices is associated with an increase in next year's food price index of almost 0.5. This is an interesting result because, in general, inflation tends to cause more inflation. However, that would not be the case here. It is possible that an increase in food prices at the previous year will reduce aggregate demand, leading to a decrease in prices in the current year. Lower prices at the present period will increase aggregate demand and exert an upward pressure in prices at the next period.

The coefficient on CaneEthArea indicates that, ceteris paribus, an increase of 1 million acres in the area planted of cane used to produce ethanol is associated with a decrease in the relative world food prices index of 0.405. This result suggests that more area allocated to ethanol production in Brazil, is likely to have a negative impact on food prices. This outcome seems counterintuitive at first and a possible explanation for it has been developed previously with respect to Regression 1 (Table 6). The rationale will be the same. The effect of the corn area allocated to ethanol cannot be determined because the coefficient for CornEthArea is statistically insignificant. All the remaining variables were insignificant. The effects of the remaining variables on relative food prices are inconclusive because their coefficients are not statistically significant.[42]

In Regression 2 (Table 8), the area variables are substituted by the corresponding first lags. In this regression, the coefficients of the lagged area terms (LagCaneArea and LagCornEthArea) were not significant; hence, the effects of past areas allocated to produce ethanol cannot be determined. Past food prices (Lag_pF/pE), have negative effects on current food prices. The interpretation here is similar to Regression 1 (Table 8).

The only other dependent variable that is found to be significant in this table is China Imports of Food. The coefficient on this variable is surprisingly negative, suggesting that an increase in China imports is associated with decreasing food prices. This is possibly because China's fast growth led to a higher import demand for processed food, switching demand away from food commodities and, hence, exerting downward pressure in the food prices index. It is important to stress that this index

[42] The adjusted R^2 suggests that 28.8% of the variation in relative food prices is explained by Regression1.

aggregates several internationally traded food commodities.[43] Similarly to the second regression, in Regressions 3 and 4 (Table 8), only the variables Lag_pF/pE and CHFood were significant and the coefficients do not diverge considerably among them.[44]

In Table 9 the intercept was included in all regressions from Table 8 to see if significant changes would happen. The intercept term was not significant in any of the regressions. The variable CHFood was no longer significant in Regression 4. Similar to what happened to Table 6 and Table 7, the regressions in Table 8 have a higher overall significance (F-test) and higher adjusted R^2, and hence, suggesting the regression through origin is a better fit for the model with the ratio between food prices and ethanol as the dependent variable.

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[43] 18% of the variation in relative food prices is explained by Regression 2, according to the adjusted R^2.

[44] The adjusted R^2 suggests that 21.8% of the variability in relative food prices is explained by Regression 3 and 18% is explained by Regression 4.

Table 9 – Regression estimates with intercept. Dependent variable: $\frac{p_F}{p_E}$

Variables	Regression 1	Regression 2	Regression 3	Regression 4
Intercept	0.061 (0.732)	0.052 (0.774)	0.007 (0.971)	-0.041 (0.818)
Lag_pF/pE	-0.461 (0.040)**	-0.598 (0.016)**	-0.680 (0.009)*	-0.517 (0.036)**
BRMktShare	1.717 (0.772)	-2.789 (0.627)	-3.735 (0.511)	-2.579 (0.671)
CaneEthArea	-0.435 (0.109)***	—	—	—
CornEthArea	0.122 (0.260)	—	—	—
LagCaneEthArea	—	-0.134 (0.661)	-0.092 (0.746)	—
LagCornEthArea	—	-0.018 (0.894)	0.002 (0.987)	—
CaneEthArea(%)	—	—	—	0.233 (0.957)
CornEthArea(%)	—	—	—	5.168 (0.589)
ExcRate	-0.015 (0.540)	-0.027 (0.313)	-0.024 (0.367)	-0.022 (0.434)
CHFood	-0.230 (0.186)	-0.333 (0.055)**	-0.349 (0.030)**	-0.283 (0.127)
OilPrice	-0.008 (0.649)	-0.007 (0.731)	—	-0.009 (0.652)
LagOil	—	—	-0.017 (0.351)	—
Adj_R^2	0.282	0.172	0.206	0.172
F- statistics	2.401***	1.740	1.929	1.740
Durbin Watson	2.271 (df=25)	2.345 (df=25)	2.348 (df=25)	2.379 (df=25)

(*, **, *** : indicates the coefficient is significant at 1, 5 or 10 percent level, respectively.)
DW critical values: df= 25, k= 8 independent variables: d_L= 0.702, d_U= 2.280.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Summary

This research explored the relationship between food prices and ethanol production. Specifically, four research questions were addressed:

1. How changes in ethanol productivity relate with food prices?
2. Are the impacts of sugarcane based ethanol and corn based ethanol on food prices similar?
3. Is the diversion of land from food production to ethanol production affecting world food prices?
4. Are energy costs, growth in developing countries and dollar exchange rates associated with increases in world food prices?

In the survey of the literature, studies on food price inflation and its link with ethanol production were presented. We also described the ethanol market, based on past research, focusing on why there has been an increasing interest for this sort of renewable energy.

This research developed a theoretical framework, discussing how the interaction between supply and demand determines the prices and quantities of food and ethanol traded in the market. It is a simple model, with two goods, ethanol and food, and one input, land. The price of food is determined in terms of the price of ethanol, which is set to be the numeraire. After the equilibrium conditions were established, we used comparative statics to predict the effect on food market prices of changes in total land and productivity of ethanol.

Next, we used time series data on ethanol production, ethanol area planted, and on macroeconomic factors to understand how these variables relate with food prices. Data was collected from different public databases (e.g. IMF, RFA, ERS) and whenever gaps in the data were found, or data was not available, contact to government departments (e.g. Brazilian Ministry of Agriculture) provided the missing data.

5.2 Results

Within the framework of the theoretical exercise developed in Chapter 3, we found that ethanol supply is inversely related with food prices and directly related with ethanol productivity and total land available. Ethanol demand, differently, is determined solely by the consumer’s income, which is exogenous to the model. We were interested in the relationship between food prices and ethanol, and the relevant outcome of the model is that an increase in ethanol productivity will have a positive impact on food prices. This result is related with the fact that ethanol demand is fixed. Hence, increases in productivity will raise the supply of ethanol. As demand does not change, higher supply will be followed by lower ethanol prices. Ethanol prices were defined as the numeraire, therefore, when referring to food prices, we are talking about food prices relative to ethanol prices, and when ethanol prices decrease, the relative price of food, with respect to ethanol, increases.

The theoretical model answers the first research question addressed. However, we also wanted to test it empirically (Chapter 4), and the variable we used as a proxy for ethanol productivity was the Brazilian share of total ethanol produced in the US and Brazil (BRMktShare). The choice of this variable as a proxy for productivity can be explained as follows. If there are two countries producing ethanol and the productivity of one country goes up, so does its market share. The Brazilian Market Share had similar effects on food prices across the regressions analyzed, suggesting that a marginal increase in this variable exerted upward pressure on relative food prices. This result is consistent with what we found in the theoretical framework, indicating that if the Brazilian market share increases, then overall productivity of ethanol increases, since Brazil is more productive than the US.

Moving a step back, let's explain the empirical model, developed in Chapter 4. It intended to capture, using regression analysis, the effects of monetary and macroeconomic factors on relative food prices. The key independent variables were chosen according with the research questions. The remaining independent variables were chosen based on the food inflation factors identified in the review of the literature. We developed two sets of regressions using two different dependent variables. In the first group, the effect on the ratio between food prices and CPI $\left(\frac{p_F}{CPI}\right)$ was investigated. In the second group another set of four regressions examining the impact on the dependent variable ratio of food prices and ethanol prices $\left(\frac{p_F}{p_E}\right)$. The second dependent variable intended to test the theoretical model, in which we had the ratio between food prices and ethanol prices.

The second research question was whether the impacts of sugarcane based ethanol and corn based ethanol on food prices are similar. In order to address these questions we collected data on land allocated to ethanol. As we were interested in comparing the impacts of sugarcane based ethanol and corn based ethanol, we used the variables Brazilian (sugarcane) ethanol area and US (corn) ethanol area. The lags of these variables were also included (see Table 4). The regression results showed that increases in area allocated to produce ethanol in Brazil (CaneEthArea) had depressing effects on relative food prices. This result was, at first, surprising, but when we looked into the correlations between the areas of ethanol, total sugarcane and sugar we found that the area of cane, and consequently sugar, has historically increased together with the ethanol area. If sugar area is increasing (concomitantly with ethanol area) the supply of sugar increases, exerting downward pressure on sugar prices, and thus, food prices. The same result was found for the lagged cane ethanol area.

We could not draw conclusions on the impact of corn ethanol area or lagged corn ethanol area on food prices because the regression results showed corn has no statistically significant effect on food prices. Consequently, we are unable to establish a comparison between the effects of cane based ethanol and corn based ethanol. All we can say here is that, according to our data, an increase in the Brazilian cane ethanol area did not contribute with the increase in the world food price index.

To answer the third research question of whether the diversion of land from food production to ethanol production is affecting world food prices, we tried to capture the effect of reallocating a food crop to produce fuel. Ethanol area, proportional to total sugarcane and corn areas, was used. However, the effect on relative food prices is inconclusive because the coefficients for the proportional ethanol areas were not statistically significant in any of the regressions. Although the variable cane ethanol area was found statistically significant (see previous paragraph), it also does not help answer question 3 because we could not capture what happens when only cane ethanol area increases, without increasing sugar area.

In the fourth, and last, research question we inquired about the relationship between the control variables and food prices, i.e. how energy costs, growth in developing countries and dollar exchange rates are associated with increases in world food prices. The proxy for energy costs was real crude oil prices. The literature suggests that oil prices are important in the food production process, especially with transportation. Consequently, higher oil prices will raise costs in producing food, which will be transferred to consumers in the form of higher food prices. This research confirms that an increase in oil prices will lead to higher food prices.

Previous studies have implied that the rapid growth in some developing countries, especially China, is resulting in a considerable increase in the consumption and import of meat and dairy products, which are important components of the world food price index. That is why we chose to use China imports of food and live animals as a proxy for growth in developing countries. The results for this variable, however, were either statistically insignificant or significant and negatively related with food prices. The negative coefficient in the CHFood variable was counter-intuitive and a possible explanation for it is that China's fast growth led to a higher import demand for processed food (which is captured by the data along with import of live animals), switching demand away from food commodities and, hence, exerting downward pressure in the food prices index.

Currency depreciation affects the relative prices of goods. Given that most world commodities are traded in US dollars, a depreciation of that currency is likely to be followed by higher food inflation. In other words, more dollars will be necessary to buy the same amount of food. The empirical analysis found a negative relationship between the dollar exchange rate and food prices, supporting previous expectations. Answering to the last question, this research found that oil prices and currency depreciation are associated with increasing food prices. With respect to China imports of food, the data shows that it has none, or very little relation with the relative food price index.

Finally, it is important to notice that the overall performance of the tested models was satisfactory as indicated by the F-test and adjusted R^2. For example, the adjusted R^2 revealed that 17.2-60% of the variation in relative food prices is explained by the regressions.

5.3 Limitations

Research in the social sciences is not without limitations. In this thesis, the main issues relate with the data. First of all, we used annual data. However, it would be preferable to have at least quarterly data on food prices, because increases in input prices pass quickly to consumers in the food sector. Hence, having quarterly or semi-annual data for food prices and the remaining variables would allow to better capture the variability in food prices. Additionally, we would benefit from a larger sample size.

The data used as a proxy for growth in developing countries did not produce very clear results. There are other sorts of data that could be used to capture this effect. Hence, trying another set of data, rather than China imports could be an option.

The data for Brazil was in general very difficult to obtain and in some occasions it was not compiled uniformly. That was the case of ethanol prices. Part of the data was available monthly and part annually. There was also a disparity in the currency unit. For the most recent years they had it in US dollars, however early data on ethanol prices were reported in the Brazilian currency of the time. Notice that the Brazilian currency changed five times over the past 30 years. We converted the whole series to US dollars and found the yearly average for the monthly part of the series.

Although we looked how the increase in ethanol areas relate with food prices, our model did not test whether the increase in sugarcane and corn areas have been displacing other food crops. This is an interesting question and ground for future research.

For lack of data, we did not control for exogenous factors such as recessions, natural disasters, droughts, or national events. However, we are aware that these events are likely to affect food prices.

5.4 Conclusion

It is noteworthy that the role of agriculture in supplying energy (along with food) is likely to increase in the future, presenting risks and opportunities for both industrialized and developing countries. The first seek less instability on energy supply, whereas developing countries are more focused on rural development, employment and access to foreign markets. Fossil fuels have been the main source of energy in many countries and are likely to remain dominant for quite some time. However, environmental issues, oscillations in crude oil prices and political instability in several oil exporting countries have brought attention to the use of alternative fuels, ethanol being the main one. Nonetheless, a careful analysis is required to assess the benefits and risks of producing ethanol in large scale, particularly the allocation of extensive amounts of land for monocultures. There is also the issue of competition for land and water with food production.

Research findings on the adverse effects of increasing demand for ethanol are controversial and studies have found that, if a rise in demand is not followed by an increase in crop productivity, food prices are likely to increase. The main purpose of this study was to contribute to this discussion and we found that, in Brazil, there is no evidence that allocating land to ethanol is upholding the inflation on global food prices. In the contrary, the production of ethanol and sugar have been so synchronized that, increases in total sugarcane area, have not favored one product more than the other. As a consequence, we saw that an increase in ethanol area was associated with decreases in food prices. A quick look at the graphical displays of the data on Brazilian ethanol area and Brazilian ethanol production shows that the Brazilian ethanol productivity increased considerably over the past years. This increase in productivity is beneficial in the sense that it allows to increase production without having to expand land use. These results could be faced as an incentive towards the production of sugarcane based ethanol.

The data did not allow establishing a comparison between the impacts of sugarcane and corn based ethanol or to draw conclusions on the relationship between corn ethanol produced in the US and food prices, because the regressions showed no statistically significant results.

The issue of raising food prices is delicate, because it has a harder impact on the poorest, whose larger share of income is spent on food. However, investing in ethanol production could also represent an opportunity for them. Developing countries, in general, have good potential for ethanol production due to land availability, weather conditions and cheaper labor. Investments in this sector could also strengthen rural economies. Additionally, the development of an international ethanol market seems especially interesting for developing countries, such as Brazil, with comparative advantages in ethanol production. Moreover, ethanol trade faces market distortions caused by protectionist policies, which may prevent the development of an ethanol industry in countries with comparative advantages, stimulating its production where it is more expensive.

The findings in this thesis will add to the body of knowledge concerning the link between ethanol and food prices. It is possible that the reader ends up with more questions than answers to the problems addressed. We hope these questions will be used as a starting point to a variety of new approaches in researching the relationship between food prices and ethanol.

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APPENDIX A

Table of descriptive statistics

Variable	Minimum	Maximum	Mean	Std. Deviation
Index Food Prices	97.61	155.06	123.06	14.68596
Food/CPI	.94	22.95	5.0843	5.84048
pF/pE	1.00	3.74	1.7090	.53112
BRMktShare	.48	.85	.7159	.11345
CaneEthArea	2.82	9.61	6.6539	1.43574
CornEthArea	0.44	21.48	5.3546	4.61630
CaneEthArea(%)	.90	1.27	1.0479	.10120
CornEthArea(%)	.78	2.01	1.1795	.28926
ExcRate	83.24	117.27	94.5825	8.90792
CHFood	1553.00	10300.00	4550.2	2458.24220
OilPrice	15.97	88.71	41.2081	20.84172

Number of observations: 28

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