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Biofuels-economical and ecological impact

Bachelor thesis

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Declaration of Authorship

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Prague, May 10, 2019

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Abstract

This thesis analyses the price transmission between biodiesel and its major feedstocks. In the beginning of the text, previous findings regarding the field of biodiesel are summarized and the feedstocks are described. The following research consist of studying weekly prices of biodiesel, diesel, palm oil, rapeseed, soybeans, sunflower seed and cotton with the use of econometric methods dedicated to time series analysis, namely Johansen cointegration test, impulse response function and vector error correction model. Our dataset covers the time period from 2003 until 2019 and includes the two biggest biodiesel markets-European Union and United States. Results of our computations suggest that the prices studied exhibited both a short and long-run co movement, whose nature changes as time passes.

Abstrakt

Tato práce zkoumá vztah mezi cenami biodieselu a olejnin. V úvodu jsou popsány dosavadní nálezy z problematiky biopaliv. Následná výzkumná část se zabývá analýzou cen biodieselu, dieselu, řepky, palmového oleje, sóji, slunečnicového oleje a bavlny. Studie zkoumá data z EU a USA mezi lety 2003 a 2019. Výsledky naznačuji jak kratkodobý tak dlouhodobý vztah mezi analyzovanými řadami. Povaha tohoto vztahu je navíc časově závislá.

JEL Classification Q42, Q54
Keywords biodiesel, price transmission, fuel, food

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Bachelor's Thesis Proposal

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Proposed Topic : Biofuels- economic and ecological impact.

Research question and motivation The issue of provision of energy for the vast population of planet Earth remains one of the biggest challenges for the humankind today. Sources such as fossil fuels are limited and will be depleted one day, so it is evident that we must seek for renewable resources to provide for our everyday needs. Even though complete depletion of fossil fuels is still quite far away, new energy resources are already on the scene. This is mainly due to environmental reasons, because fossil fuels are in fact believed to be the worst possibility from the ecological point of view. One of the frequently used renewable resources are biofuels, however these are subject to controversy because of their different impacts on the nature.

Contribution The thesis will try to answer the question whether the use of biofuels is the right choice for the protection of the environment. If so, it will also try to find ways to minimalize the negative externalities coming from their use. Its contribution to the issue will lay in the attempt to predict and discuss the role of the biofuels in the future. Moreover, it will examine possible economic and ecological effects of new legislation, such as the decision of the European Parliament to ban the subsidies on fuels made from palm oil. In practice, ideas of this thesis can help to study profoundly the overall effects of government actions in the field of fuels.

Methodology The thesis will look at the issue from the global as well as regional perspective, hence working with both global and local data. This method will allow it to compare different markets and legislative approaches. It will try to examine potential relationships between economic and natural data. The thesis will test the effectivity of government subsidies and regulation and their environmental numerically quantifiable results, for example amount of pollution from transportation. Data will be continuously extracted from the Internet during the research, so that actual trends can be observed. Government agencies offer significant amounts of data, among others the Economic Research Service of the United States Department of Agriculture. The analysis of the data will be done with the use of statistical and mathematical softwares, for example Rstudio or Mathematica. Following hypothesis will be tested:

- 1) There is a positive association between the amount of land used for the production of biofuels and the price of basic foods.
- 2) Financial support of biofuels ameliorates the living conditions on Earth.
- 3) The amount of biofuel produced is positively corelated with the intensity of pesticide usage.
- 4) The same volume of natural gas compared to amount of biofuel would lead to higher ecological improvements.
- 5) The production of palm oil will not decrease significantly after the EU subsidies terminate.

Outline The thesis consists of two main parts. In the first, the effect of government support of biofuels is studied. It examines how subsidies and tax cuts affect the price, demand, supply and other economic indicators of biofuels. It discusses the effects on the market and competition. In the second part, it will focus on the environmental impacts resulting from the production and use of biofuels, attempting to quantify what they actually bring to the ecosystem. Finally, it finds possible links between legislation and market mechanisms on one side and actual environmental phenomenons on the other. List of academic literature:

Bibliography

- 1) The Impacts of Biofuels on the Economy, Environment, and Poverty. David Zilberman

- 2) http://ec.europa.eu/eurostat/statistics-explained/index.php/biofuels
- 3) Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emission from Land-Use Change. Timothy Searchinger et al.
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- 5) Environmental, economic and energetic costs and benefits of biodiesel and ethanol biofuels. Jason Hill et al.

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Chapter 1

Introduction

The fundamental consequences that were expected from the implementation of biodiesel into our fuel system was indeed the decrease of transportation emissions, increase of energetical independence and the development of rural areas. As the issue of changing climate seems to be more urgent in the last years, many governments hope that further increase of biodiesel production might save us from further damaging our environment. Additional expansion of biofuels might decrease emissions of greenhouse gases, reduce the dependence on fossil fuels and ameliorate the well being of people living on the countryside, nevertheless producing and consuming biofuels also has its downsides. Firstly, it seems to be uncertain if biofuels from overall point of view actually bring significant improvements to our ecosystem. This is especially the case for the first generation of biofuels. The main economic worry is that since the making of biofuels requires agricultural commodities, increased production of biodiesel puts pressure on the food market, as more land and plants are dedicated for our fuel tanks instead of our nourishment. If any of these worries are proven to be legitimate, then it might be valid to question if the implementation of biofuels leads to an overall improved well-being of the human civilizaiton.

The objective of this thesis is to investigate the interconnections between the price of diesel, biodiesel and its major feedstocks using time series analysis. The thesis is structured as follows: Chapter 2 summarizes the literature findings regarding price transmission of biodiesel, then describes the policies that concern biodiesel and explains their impact, and finally looks at the environmental effects of biodiesel production. Chapter 3 describes in more detail the biodiesel feedstocks whose price behavior will be studied further on. Chapter 4 introduces the analytical tools that are used to study the price transmission.

Chapter 5 presents the findings of the analysis and brings possible interpretations. Finally, chapter 6 concludes the outcomes of the research and suggests possible areas for further work regarding biodiesel.

Chapter 2

Literature review

Biodiesel is a chemical compound that influences human life in many aspects. The complexity of its influence indicates that it is necessary to organize the findings about biodiesel impacts into several categories. In this thesis, the organization is done in the following manner: first part of the literature review introduces basic information about the biodiesel industry, then deals with the economic impacts of biodiesel and biofuels in general. The economic impacts are divided into two subsections- premierly, we summarize findings about price transmission regarding biodiesel and then we look at other economic aspects of biofuels. Second part of the literature review examines the role of governmental actions in the biodiesel market. Last part brings the evaluation of environmental impacts of biofuels, attempting to express what they bring to the ecosystem.

2.1 Economic impacts

Large number of studies examining the relationship between the price of biodiesel and its related commodities was performed until now. Most of these studies focus either on US or European markets, due to their importance in terms of volume of biodiesel produced in these regions. In fact, to better understand the regional dependency of biodiesel, it is useful to first look at the evolution of the biodiesel market and its production numbers.

In 2017, the world biggest player in the biodiesel market were by far United States with 6 billions litres produced. Brazil took second place with 4.3 billion litres, followed by Germany (3.5 billion litres) and Argentina (3.3 billion litres). Other considerable biodiesel regions are China, France, Indonesia, Thailand or

Spain. Africa seems to be the last big region where the biodiesel hype has not taken place yet. Note that if we consider European Union as a single market, then EU was by far the biggest biodiesel producer and consumer by far with over 15 billion litres made (Statista (2019)). All these numbers seem to be immense, but it is good to put them into perspective. In 2017, the oil consumption in the European Union was 645 million tons for the whole year, with one tonne of oil being approximately 1,400 litres. Comparing this number with the 15 billion litres of biodiesel, we can say that under current energetic circumstances, there is a drop of biodiesel in an ocean of oil.

It is also of our interest to describe how biodiesel and food prices are linked. Suppose that a certain government decides to raise the obligatory amount of biodiesel that has to be contained in the fuel sold at the gas station. As the demand for fuel keeps increasing in a stable manner, due to population expansion and economic growth, this by consequence leads to higher demand for biodiesel feedstocks, which are in vast majority vegetable oils. This demand is satisfied by the producers of vegetable oils, but as they cannot increase their production in short period of time, they have now left less of oil that they can sell to people as food. It is necessary for humans to consume food, so the demand for it is inelastic, therefore the shortage of supply leads to higher prices of oil that is being sold to consumers. Otherwise said, vegetable oils become a necessity for fuel retailers, while at the same time being a necessity for food consumers, which results in higher demand, which results in higher prices. To what extent this described phenomenon occurs in reality is subject to academic discussion and the following lines summarize what has been discovered until now.

Let us look more closely on the literature about price transmission regarding biodiesel. Most recent summary that encapsulate findings about price transmission of biofuels is provided by Janda & Kristoufek (2019) and an older yet very informative summary was made by Serra & Zilberman (2013), so for more detailed information, please refer to these papers.

Considerable amount of articles confirms the existence of long run relationship between biodiesel and its feedstocks- from recent years, we can mention for example Lajdová *et al.* (2017), who finds that palm and rapeseed oils influence the price of German biodiesel, whereas influence between biodiesel and soybean oil is simultaneous. This finding were previously extended by Bentivoglio *et al.* (2015), who discovers that there exists a mutual interdependence between German biodiesel and rapeseed oil for the time period 2005-2007. The study of Lajdová *et al.* (2017) also states that crude oil prices have a strong impact on biodiesel prices. Interplay between biodiesel and its fossil counterpart is a feature found by other papers as well. Such finding is quite intuitive- since biodiesel is blended with diesel made from crude oil and moreover, crude oil is utilized in biodiesel production, these two prices are likely to share similar trend in the long run. Palm oil biodiesel is also examined by Mueller (2017), who concludes that for the years 2009-2013 biodiesel reacted to shocks in palm oil and crude oil prices, while palm oil reacted only to biodiesel shocks. For the case of Spain, Hassouneh *et al.* (2012) find that Spanish biodiesel is positively correlated with sunflower and crude oil, but biodiesel is the only one of the three commodities that adjusts to any shocks to the long run equilibrium. Another examination of the Spanish market is performed by Serra & Gil (2012), who concludes that there is an asymmetric dependence between crude oil and biodiesel, whereas the dependence between crude oil and diesel is symmetric. The long run relationship between biodiesel and rapeseed is confirmed by Bentivoglio *et al.* (2015), who say that European biodiesel prices are strongly affected by rapeseed prices, but the reverse effect is of weak nature. Vacha & Barunik (2012) analyze biofuels and related commodities for the time period 2003-2011 with the use of wavelet coherence. They find high level of correlation between biodiesel and German diesel and note that the structure of correlation is time dependent, mainly changing during the food crisis of 2008. Baier *et al.* (2009) estimates that in the pre-food crisis period, i.e. between the years 2006 and 2008, biofuels production caused the soybean prices to rise by about 15%.

Papers that only study the link between crude oil and agricultural commodities are also written frequently, suggesting that rather than biofuels, crude oil might actually be the main driver of higher food prices. Obadi & Korček (2014) finds long run causality flowing from crude oil to food commodities. However, Yu *et al.* (2006) arrived to the opposite conclusion, which is that crude oil prices do not have strong impact on vegetable oils prices. Since similar methods were used in the studies, this suggests that the link between oil and food might be a rather new phenomenon. Pal & Mitra (2017) point out that between 2004 and 2014, when soybeans prices are high, their reaction to diesel pries is significantly stronger. Peri & Baldi (2010) study if diesel and several vegetable oils prices are cointegrated and concludes that the long run relationship exists only between diesel and rapeseed oil.

Papers that refuse the link between biofuels and food prices also exists, for example Cooke Miguel Robles *et al.* (2009), who say that the rising food prices of 2006 should not be attributed to increased biofuels production, but rather to financial activities on future markets. Same idea can be extracted from the paper by Gilbert (2013), who criticizes the lack of direct evidence for biofuels causing higher food prices and also points to investments on future markets with agricultural commodities. The price transmission between biofuels and food commodities is also dismissed by Gilbert (2013)- the authors states that for the case of Germany, biofuels cannot possibly explain the increased volatility of agricultural commodities prices.

To conclude about the price transmission regarding biodiesel, majority of the studies that have been published until today tend to agree on the existence of a price link between biodiesel and its feedstocks, however the characteristics of this link seem to depend on the time period, region and feedstock that is being studied.

Following lines mention economical studies that examine other economic features of biodiesel apart from its price transmission on other commodities. Manaf *et al.* (2019) takes the example of soybean oil biodiesel and points out that the evolution of total variable cost and total cost of producing this kind of biodiesel follows quite closely the trend of the soybean oil price, which indicates that the break-even point of the industry will strongly depend on the feedstock price, therefore the profit of the refineries will hinge on the behavior of soybean oil market. Their data also suggest that the total variable costs changes almost only because of feedstock price fluctuations, meaning that other variable costs change only to a small extent over time. It is not unlikely that these concepts will be valid for the biorefineries in general, meaning that the success of producers of biofuels depends on the prices of the feedstock they use. This explains why biodiesel market is so narrow in terms of feedstock choice- vast majority of biodiesel made from vegetable oils is nowadays produced from only three commodities- rapeseed, soybeans and palm oil. The reason for this is that those feedstocks are the cheapest and most effective to produce from all the possibilities. Biorefineries do not have any incentive to change their offer as this would not change the demand for their products because consumers do not really care if the fuel in their tank is made from rapeseed or soybeans. Accounting for this, first generation biodiesel market will therefore probably remain dominated by several products in the next years.

Taheripour (2010) brings another interesting insight on how the business of biorefineries works. The refineries benefit from the fact that during the production of biodiesel, there is a byproduct created- it is the distiller grains. These grains can be further sold, especially as cattle feed. The word byproduct suggests that it is not too important, but according to the study mentioned, it plays a very important role in the biodiesel business- the sales of distiller grains contribute to the revenue of a rapeseed based biodiesel refinery with 23%. For soybean biodiesel, this number raises to 53%, so in that case, it can be said that biodiesel is the byproduct and distiller grain is the core of the business. Success of biorefineries will therefore not only depend on the demand for biodiesel, but also on the demand for animal feed. However, there are no signs that production of animal based products should decline in the following years, so biodiesel business seems to be safe from this point of view.

Economic papers regarding biofuels of further generations do not bring much optimism about near development in biofuels production. Second generation of biofuels is made from non-edible plants or animal waste and in comparison to first generation biofuels, they evince higher emissions savings and also avoid the food versus fuel issue. Carriquiry *et al.* (2011) examine the potential of second generation biofuels produced from several feedstocks. They find that the median cost of biodiesel produced from algae is seven times higher than the cost of diesel in 2011. Note again that we are now in 2019 and yet after 8 years, there has been no significant cost reduction of producing further generations of biodiesel. Authors also mention that for second generation biofuels, the cost of feedstock represents smaller proportion of the total cost of production compared to first generation. Any innovation in the production process would hence lead to a significant reduction of total cost for the second generation biofuels.

As a final word, we can say that the price transmission between biodiesel and vegetable oils has been studied quite profoundly, especially after the awareness about this issue increased with the arrival of the food crisis. This intensive research is compensated by a lack of knowledge about other economic aspects of biodiesel, for example about investment in biorefineries and their profitability. Such concepts could then actually be linked to the study of price transmission of biodiesel, hence allowing for more complex knowledge about how the biodiesel price system works.

2.2 Legal impacts

Without any exaggeration, we can say that biodiesel market would most likely not exist without the existence of specific legislative support. Following lines describe the current EU and US biofuels policies and explain their possible impacts.

Since vegetable oils are more expensive (1,5-2 times) than diesel, it is logical biodiesel made from them is not able to compete with petroleum based diesel unless some kind of financial and regulatory aid is provided by the government (Ahmad *et al.* (2011)). The support varies depending on each state energetic strategy and ranges from subsidies and tax exemptions to mandatory blending of biodiesel into the fuel that is being sold at the gas stations.

When support for biodiesel started in the end of the last century, its main goal was not the fight against climate change (Zilberman *et al.* (2014)). Instead, politician seek to improve the balance of trade of their countries by producing and consuming biodiesel domestically, hence allowing them to export fossil fuels. This was especially the case for the US biodiesel market. Currently, the core US policy regarding biofuels is the Renewable Fuel Standard, which states an amount of renewable fuels that must be blended and sold every year. The amount is increasing every year and will end up being 36 billions of litres in 2022. Since United States produced 6 billions of litres of biodiesel in 2017, this mandate will probably be in majority full filled by ethanol, which is the dominant renewable fuel in the USA.

The main EU policy regarding biofuels is called the Renewable Energy Directive. This legal document sets the target to have 10% of fuel consumed in EU coming from renewable resources. There is a notable difference between the EU and US approach- EU expresses its target as the proportion of the total fuel consumption, whereas US sets a fixed amount, no matter what the consumption of fossil fuels will be.

The EU policy is implemented in the following manner: European commission obliges the member states to reach the target. Member states then have to implement national laws that will make them reach the target. This laws in short consist of telling the fuel retailers that they have to use at least 10% of renewable resources in their fuel mix. The fuel retailers then buy from biorefieneries the biofuels and add them into the fossil fuel and sell the blend at the pump. Finally, every driver contributes to reaching the target by buying fuel at the gas station. The European support for biofuels is immense. According to Charles *et al.* (2013), in 2011 approximately 46% of all worldwide biofuels subsidies were given out in the EU, with every litre of biodiesel being supported by around 0,44-0,51 EUR. The study from Charles *et al.* (2013) also points out that it is up to every EU member state how to achieve the emissions target. Some countries choose to import the majority of biodiesel and feedstocks from abroad- for example Spain, who in 2010 imported almost 90% of its feedstock from Argentina and Indonesia, but countries who rely majorly on their own production also exist, such as the Czech Republic. These decisions depend on the local political representations as well as on the decisions of fuel retailers and might also be connected to international relations of every state. It should be also mentioned here that the whether a country will produce produce biodiesel or rather import it might to some extent depend on the domestic demand for agricultural commodities. If citizens prefer to buy local fruits and vegetables, even at the expense of higher prices, then framers will satisfy the demand and there will be less land left for the production of biodiesel feedstock, hence biodiesel or the feedstock will have to be imported. If, on the other hand, people prefer cheap food over local food, local farmers will be more likely to decide to plant rapeseed and profit from the stable demand for biodiesel caused by the European law.

European Union also implemented sustainability criteria that the biofuels utilized need to keep up with. Nevertheless , there are worries that these criteria are in fact a barrier from trade, especially for countries such as Thailand or Malaysia, who could otherwise have greater benefit from the EU policies.

The principal problem in the current European legislation is that it does not give the member states much choice how to achieve the energy mix target. Under the current circumstances, which means insufficient resources and absent technology, the fuel producers can do nothing else but buy or produce first generation biofuels. The policy of double counting aims to motivate the member states to produce biofuels of further generations that do not affect food markets, but unfortunately for now, as already mentioned, technologies for their production are insufficient. Concerning the method of double counting, policies regarding biodiesel implemented by the European Union are scrutinized by Boutesteijn *et al.* (2017). Two different policies are included in the study- blending mandates and double counting of second-generation biodiesel. Blending mandate sets an obligatory amount of biofuel that needs to be mixed with the petrol based fuel when sold to customers, double counting method states that energy coming from second-generation biofuel can be counted as two times the amount of energy coming from the first generation. This would hypothetically mean that a member state could only produce only half of the energy coming from biofuels to reach the EU mandate if he was using solely second-generation biofuels and not any first-generation ones. Boutesteijn and his colleagues show that the two policies can in fact have opposite impacts- blend mandates increase the use of first-generation biodiesel at the expense of the second-generation one, whereas the double counting has the reverse effect and also raises the consumption of petroleum base diesel. These findings support the opinion of critics of European renewable policies, who say that it is ineffective and might be counterproductive. Another examination of EU policies is done by Drabik & de Gorter (2014), who estimates the effect of biofuels policies on oil seed prices in the case when a shock to diesel prices occurs and find out that this shock causes smaller increase in vegetable oil prices under a blend mandate than under a tax exemption.

To summarize, policies that support biodiesel are at the moment a necessary assumption for the survival of this commodity. The overall improvements resulting from this policies are uncertain, especially from the ecological point of view, as will be shown in the next section.

2.3 Environmental impacts

This thesis is trying to set itself apart from standard economic papers about biofuels, where the environmental impacts of biofuels are given no or little attention. The absence of evaluation of environmental effects of biofuels is a pity, because having a stable ecosystem is a an essential condition not only for the production of biofuels, but for the development of human civilization in general. Weather trends from recent years suggest that our agricultural production may find itself under unprecedented pressure in the close future, especially because of erosion and depleting water resources. In this context, radical changes in our agricultural, transport and energy systems seem to be inevitable.

Two of the most obvious environmental impacts of biofuels are on our atmosphere and on our land. From the general point of view, impacts on atmosphere should be positive and those on the land are expected to be negative. Regarding the air, there is a large number of studies that examine how using biodiesel in standard engines affects the amount of emissions being released. Kim *et al.* (2018) examine the performance of rapeseed biodiesel and finds out that in its pure form, i.e. B100, this kind of biodiesel saves about 35,4% emissions when compared to fossil diesel. Palm oil based biodiesel evinces similar CO emissions savings, estimated to range between 30% and 46% (Shote *et al.* (2019)). Study of Özener *et al.* (2014) appraise the carbon monoxide savings of soybean biodiesel to lay between 28% and 46%, however the authors also add that the carbon dioxide emissions increased a little (by 1,5-5%) for the soybean biodiesel blend. Environmental consequences coming from the production of rapeseed and soybean biodiesel are explored by Ziolkowska (2011). Firstly, the author says that the positive impacts of biofuels are due to their consumption, while the negative ones come from their production. This means that the benefit of potential emission saving has, apart from the market price also the price represented by the use of agrochemical products or land use change. The author then try to quantify the positive and negative effects. They estimate the CO2 emissions saving due to biodiesel use between the years 2006 and 20118 to range between 52,6 and 78,8 million tons for the US and 115,4-173,1 million tons in the EU. However, looking at the annual CO2 emissions coming from the EU, we can see that those amounted to 4441 million tonnes in 2018, which raises concerns if biodiesel brings noticeable improvements to the climate, given what effort is focused in their production. Concerning the negative effects, the authors approximate the fertilizers use due to biofuels production. For the US soybean production, 1173,2 million kg of fertilizer were used between 2006 and 2011.

The studies regarding the emissions savings that were mentioned so far have one common feature- they were experimental studies performed in a laboratory setup, or in some other way they did not take into account the fact that biodiesel needs to be produced, transported and sold. These activities directly involve the use of biodiesel, therefore it is fair to include them in the emission counting. The approach that takes into account the whole process of production and consumption of biodiesel and estimates its impact on the environment is called Life Cycle Assessment. As the name suggests, this technique consider every single stage of life of a certain product and asses its impact on the environment. For biodiesel, the life cycle goes as follows- firstly, the feedstock is planted, cultivated and harvested. Then comes its transportation to the biorefinery, potentially preceded with further processing. In the refinery, the biodiesel is made and then finally transported to consumers, who fill their tanks with it. Studies regarding LCA of biodiesel, such as the one from Rajaeifar *et al.* (2014) indicate that the stages that cause the most emissions are the production of the feedstock (about 50% in the study previously mentioned) and the conversion of the feedstock into biodiesel (about 33%) of the emissions. Consequently, De Marco *et al.* (2016) suggest that more sustainable fertilization and the use of biodiesel in agricultural machines that are used during the production of biodiesel might improve the environmental impact quantified by LCA. Any innovations in these process of biodiesel production will therefore reduce its negative environmental impacts. In this context, it is also evident that biodiesel from imported feedstocks (such as palm oil for both EU and US or soybean oil for EU) will have significantly lower environmental benefits since its transportation requires burning of fossil fuels.

Recent papers show that Life Cycle Assessment might bring completely different conclusions about the emissions savings resulting from the use of biodiesel, especially if another evaluation standard is added. The standard is called Indirect Land Use Change and indicates that when evaluating emissions savings of biodiesel, one must take into account the condition under which specific feedstocks are cultivated. This approach notably decreases the net environmental benefits of biofuels coming from areas where rainforest can be found, especially Malaysia, Indonesia or Brazil. Due to their density that is caused by frequent rains, rainforest are probably the best tool in the fight against climate change nature has provided us with, as they are able to absorb great amounts of CO2. Amazonian rainforests are able to absorb about 2 billions tons of CO2 every year (Oskin, 2018). Logically, such numbers do not sound well for a popular biodiesel feedstock, palm oil. According to Transport & Environment (2016) , palm oil biodiesel is three times more polluting than standard diesel, exactly for the reasons mentioned before. Same agency says that soybean biodiesel is twice as polluting as fossil diesel and emissions coming from the use of rapeseed biodiesel are 118% of those of diesel.

An issue in the agricultural production of nowadays are the depleting water resources. In this context, Drabik (2017) suggests that for a fixed production of biofuels, the amount of water used decreases with increasing proportion of biodiesel in the total share. Feedstocks for biodiesel are therefore less requiring on water resources than ethanol feedstocks. In the future, water requirements of biofuel production might become a key aspect in decisions about which feedstock should be used. As Drabik (2017) indicates, the numbers are in favour of biodiesel.

The study by Hill *et al.* (2006) compares corn ethanol with soybean biodiesel and brings an important message- the amount of nitrogen, traditional fertilizer, required to produce a fixed amount of energy from a biofuel is 100 times lower for biodiesel. Regarding pesticides, the production of soybean biodiesel requires about 10 times less of them than the production of corn ethanol. Moreover, biodiesel also wins in the discipline of emissions savings- biodiesel brings 41% GHG emissions savings, whereas ethanol only 12% (note here that this study again does not compute with all the emissions that are produced when biodiesel is made). These differences are due to the fact that the conversion of soybeans into biodiesel is more effective and shows the dependency of environmental effects on specific feedstock, which will be further underlined later in this thesis. Such a finding is valuable if we take into account the fact traditional diesel engines are more pollutant than traditional gasoline engines. This issue could, based on the study mentioned, be overcome by blending more biodiesel into fossil diesel, in order to equalize its environmental impacts in comparison to gasoline. Solving the problem this way seems to be more socially just than the solution some cities are starting to implement, which is banning old diesel cars, which is especially harmful for people with lower income that cannot afford a new vehicle.

The environmental issue linked to the frequently criticized palm oil production is actually to some extent similar to the one that European and American agricultural methods are causing- it comes from the large scale production. This kind of production without doubt brings greater efficiency, but, mainly in agriculture, brings also problems. Logically, large scale production requires large areas of land. In order for the planting, watering, fertilizing and harvesting to be the most effective, this land is adjusted to be as uniform as possible. This uniformity essentially blocks the possibility for any form of wild nature to exist on the fields- it reserves the space entirely for the one plant that is chosen. Such an approach to cultivation also limits the ability of earth to retain water, as the absence of any natural barriers causes the water to flow away quickly, washing down pesticides as well. Recent study by Hallmann *et al.* (2017) brings unhappy news about the development of our ecosystem- in Germany, in the last 27 years, 75% of the total insect biomass disappeared. Due to the landscape similarity, approximately the same numbers could probably be observed in many other European countries. Insects play a crucial role in the nature, serving as nourishment for thousands of species and pollinating many kinds of plants. The authors say that modern agricultural methods should take big part of the blame for the problem, mainly due to the previously mentioned chemization and continuing expansion of the fields. However, biofuels probably should not be criticized for the state of our fields, as this issue arises in the food production in the same manner. There are several causes for the unsustainable approach to the agriculture nowadays, and the EU could actually be accused of it to some extent. For a moment, let us bring back the issue of policies. European agricultural subsidies, which represent a considerable share of the total EU budget- for the years 2014-2020, farms will receive 363 billion euros out of the total 960 millions (Reuters, 2013). The subsidies are distributed based on the area that a farm operates on. This policy gives greater advantage to big farms, as they having larger fields does not increase expenses proportionally, but their income is improved by the generosity of EU. Another cause of the worsening state of our fields is the fact that many agricultural companies do not own the land they operate on. As conclusion, they do not care what happens to the land in the future, as they would if their family owned it for many years.

To summarize the environmental effect of biofuels, the question if biodiesel brings emissions savings remains unanswered. Some studies about biodiesel of first generation could serve as ideal examples of data misinterpretation by stating conclusions without taking into account all the factors. If we consider all the various events that occurs during biodiesel production, first generation biodiesel does not look like a perfect ecological alternative for fossil diesel. Situation like this indicates that in the future all the potential renewable resources should go through very detailed and independent research for their environmental impact. The most suitable scientific approach seems to be a profound Life Cycle Assesment.

Biodiesel might bring emission savings, however this depends strongly on the feedstock utilized and on the manner the feedstock was cultived. For the context of our study, palm oil and soybean based biodiesel seem to be most problematic, due to the fact that there are cultivated in potentially precious natural areas. Big advantage of the possible emissions savings is that biofuels are easily implemented into current infrastructure of gas stations and engines running on oil. This is their big plus in comparison to other potential resources of renewable energy in transportation, such as hydrogen or electricity. Main environmental issue of biofuels is linked to the modern means of agricultural cultivation and the decrease of areas reserved for wild nature. This issue is especially evident in the palm oil biodiesel production. Nevertheless, this is not the fault of biofuels, but of the agricultural production in general.

Chapter 3

Feedstocks

This section presents in detail the biodiesel feedstocks that are analyzed in the empirical part. The knowledge about the specific kind of feedstock and its features is crucial to understand its role as food and as fuel, because different plants have different characteristics that are important for nutrition as well as for the energy sector, such as yield per certain area, requirements for production, nutritional values or chemical properties. These information should be taken into account in specific cases when deciding which plants should be implemented as biodiesel feedstock. To give an idea about the importance of the described commodities as biodiesel feedstock, we include most recent information about feedstock composition- according to Flach(2017) , in 2017, the total European biodiesel production was composed from following commodities in following proportions-

1. rapeseed with 46% of the total share
2. palm oil with 19.4%
3. used cooking oils with 18,7 %
4. animal fats with 8,5%
5. soybeans with 4,6%
6. other vegetable oils, including sunflower with 2,6%

In United States in 2016, feedstocks were used in following proportions-

1. soybeans with 55% of the total share
2. used cooking oils with 13%

3. corn with 12%
4. rapeseed with 10%
5. animal fat with 10%

Note that the following list only describes the feedstocks that are relevant for our research, i.e. rapeseed, palm, soybean, cotton and sunflower oil.

Rapeseed oil is a dominant biodiesel feedstock, mainly in the European production. Its popularity comes from the fact that rapeseed yields more oil per hectare than other feedstock candidates and also freezes at lower temperature than them, hence its use as a fuel is possible also in winter periods and colder regions. The potential of this plant is limited by the EU restrictions on genetically modified varieties of rapeseed, which are know for overall better performance in cultivation, such as higher yields or better resistance against pests. Changing climatic conditions suggest that the implementation of GM organisms will become a necessity in order to keep up or increase current agricultural production. Proponent of rapeseed claim that this plant has many advantages- the plant has deep roots, which enables it to reach deeper resources of water and makes it more resistant against droughts. However, this also raises the question if cultivation of rapeseed does not lead to faster depletion of water and nutrient resources. Another advantage comes from the fact that when rapeseed is harvested by modern machines, they only collect the part with the seed and leave the rest of the plant on the field. This leftover biomass the degrades on the field and serves as a fertilizer for following years. The major disadvantage of rapeseed is its poor immunity against diseases and pests, which is being solved by intensive chemization of the fields. This approach is well known to endanger biodiversity, human health and water sources. There is also criticism that rapeseed production suits perfectly big agricultural companies, which use the unsustainable model of a big farm with large fields. Thanks to current biodiesel policies, farmers do not have to worry that there would be no demand for the rapeseed harvest, which makes its production practically risk-free.

Palm oil yields per hectare are by far the highest among potential plant based biodiesel feedstocks. In 2006, palm oil production cost was the lowest among oil producing plants, followed by soybean oil which was about 20% more expensive (Thoenes, 2006) The specific requirements for palm cultivation cause that majority (about 80%) of worldwide palm oil production comes from only two countries- Indonesia and Malaysia. In Europe, the consumption of palm oil biodiesel is on a swift rise in the recent years. According to Transport & Environment (2016), the share of palm oil used for biodiesel production in the EU rose from 8% in 2010 to 45% in 2015. If we study the composition of use of palm oil in EU, we can see that all the growth in palm oil usage can be in fact attributed to biodiesel production, the volume of palm oil used would otherwise be decreasing in this period. The use of palm oil raises concerns both among the public and environmental experts, worrying that palm oil production causes deforestation and diminishing biodiversity. In the last few years, many people have started to boycott products that contain palm oil, however, if they have a diesel car they cannot completely avoid it since fuel dealers are obliged to blend a fixed amount of biofuel into the fuel, however it is impossible to obtain information about the origin of biodiesel feedstock at the pump. This issue unfortunately limits the power of the consumers to economically support specific environmental policies that they personally find useful.

Labour is the costliest input in the palm oil production (which is quite unusual in oil production)- this is due to the nature of palm oil plantations, where the use of heavy machinery is limited and most of the processes must be done by human force. Small farmers also represent a chance to make the palm oil production more sustainable- they create small plantations that are dispersed over a large area of rainforest, which endangers the ecosystem less than large scale plantations for which thousand of hectares of rainforest are burned down.

According to Flach (2017) , the biggest palm oil biodiesel producers in Europe at the moment are Spain, Italy, France and the Netherlands. They use an unusual strategy in meeting their emission targets- producing biodiesel from imported feedstock to meet EU mandates, while keeping their arable land for food production, hence partly avoiding the food vs. fuel issue. Mainly for the southern European countries, the reason to do this is the ability to grow enough alimentary products that will bring them higher profits than growing biofuels feedstocks. Almost 75% of total EU palm oil imports came to Europe from Indonesia, Malaysia and Thailand in 2017 (Copenhagen Economics (2018)). If we consider crude palm oil imports only, the share of these 3 countries rises to 95%. The key message from those number is that while these Asian countries do well in producing palm oil, they do not have a sufficient network of biodiesel refineries to be able to satisfy the European demand. This is in the end not a problem for them, since palm oil will not be counted towards the EU renewable targets anymore, hence its implementation as biodiesel will stop. Nevertheless, this should not worry palm oil producers that much, because due to its nutritional properties, this commodity will surely find other markets.

Soybean oil is also an important biodiesel feedstock, mostly in the United States, where soybean is largely cultivated. In 2018, soybean oil represented approximately 65% of total consumption of edible oils in the United States, making it the most largely used edible oil in the country. Interestingly, EU accepts imports of Argentinean biodiesel made from soybean oil, but on the other hand refuses US imports of biodiesel from the same feedstock, stating that it does not comply with its sustainability standards. One could polemize if it really is the case or if it has more to do with current trade tensions between EU and the US. From the environmental point of view, soy represents an important substitute for meat, whose production causes a high percentage of globally produced emissions. What is left after the production of soybean oil is called soybean meal and can be used as animal feed, therefore the production of soybean biodiesel creates a by-product that can be further sold and that is also part of the biorefineries business.

Cottonseed oil is basically a by-product of cotton production. The main user of cotton is the textile industry. Amount of biodiesel made from cottonseed is negligible at the moment, which is quite surprising given that having both a textile factory and a biorefinery at the same place would make sense economically. Besides biodiesel production, cottonseed oil is also implemented in chemical and food-processing industry. If this oil becomes more important in biodiesel production, it might be interesting to observe the possible interaction between biodiesel and textile industry. Cottonseed oil is popular in nutrition, mainly due to two of its aspects- firstly, it has a weak taste and odor and hence does not fight with the taste of the meal it serves to prepare. Secondly, it is a stable oil, meaning it does not require creation of trans fatty acids in order to be suitable for frying. An issue linked to cottonseed oil is that in some cases cotton is not considered a food plant, therefore its production has lower regulatory standards when it comes to herbicides and pesticides safety, leading to toxicity issues.

Sunflower seed oil biodiesel was in 2016 mainly produced in France and Greece, who contributed by 81% to the total EU production coming from this oil (Flach, 2017)

As a fuel, sunflower oil does not function very well in colder temperatures. This is compensated by its nutritional qualities, hence this oil is used for frying, or the consumption of the raw seeds is also popular.

Finally, since the core of first generation biodiesel economics is the food or fuel question, allow for a note about vegetable oils in nutrition. From this point of view, it is more of a food and fuel question, because as was already mentioned, the outcome of biodiesel making is not only the fuel but for the major feedstocks also the meal that is eaten by animals that are then eaten by humans. Vegetable oils contain a chemical compounds called essential fatty acids. The word essential refers to the fact that human body needs them in order to function properly, nevertheless it is not able to produce them itself and we need to intake and digest them. Since nutritionist warn that the average human consumption is not sufficient, it would probably be beneficial to fill ourselves with more vegetable oils rather than filling our cars with them.

Chapter 4

Data

4.1 Data description

The dataset for this study consist of weekly prices of the following commodities: European biodiesel, US biodiesel, US diesel, German diesel, palm oil, rapeseed, soybeans, sunflower seed and cotton. The position of each of the feedstocks in the food and fuel markets is described in Chapter 3 . The series were obtained via Bloomberg Terminal, summing up to 797 observations for each commodity. All the price series are of weekly frequency, ranging from 21/11/2003 until 22/2/2019. The long time range of the dataset allows us to study the different periods in the evolution of the biodiesel market, notably the food crisis of 2008. The prices of US diesel and German diesel are average retail prices collected at gas stations. The prices of EU biodiesel and US biodiesel are commodity spot prices. The prices of the remaining agricultural commodities are commodity futures and their closing price is used. The prices are given for several different units: US diesel in gallons, German diesel in litres, soybeans in bushels, cotton in 50,000 pounds. Remaining prices are given per tonne. Prices series were initially expressed in various currencies. To eliminate the effects of exchange rate fluctuations in the system, the series were converted into a single currency- US dollars for American market and euros for Europe. For the purpose of conversion, we extracted the exchange rate for each date input in the dataset (from the website investing.com) and the given price was multiplied by the exchange rate.

German diesel is included to represent the evolution of diesel prices in Europe. German origin is chosen due to the size of the German economy and to the German consumption of fossil fuels- in both aspects, this country is the number one in Europe (Statisticstimes.com (2019)). Summary statistics are provided in the Table 4.1. In this table, prices of US diesel and biodiesel are expressed in USD, remaining prices are in EUR.

Logarithmic transformation is applied to all the price series, because this kind of transformation causes the data to closer approach the normal distribution, which is useful for further analysis. The possibility to interpret results in terms of percentage points is also convenient. This transformation was used in previous studies regarding the price transmission of biofuels, such as the one from Filip *et al.* (2017). Another inspiration from the study mentioned is that the dataset is divided into several subsections. Premierly, we naturally distinguish between the European and American market, meaning that EU diesel and biodiesel are separated from their US counterparts. For both markets, identical feedstocks are included. Firstly, we perform all the econometric analysis on the whole range of data. However, previous studies indicate that the evolution of the price links depends on the time period being studied, so our second distinction is in terms of time- we will also study the food crisis period individually. The time distinction is derived from the FAO price index. This index computes weighted average of prices of 5 food baskets- cereal, vegetable oil, meat, dairy and sugar. Since vegetable oils are included, it makes sense that the evolution of the index will be similar to the evolution of prices in our dataset. The peaks of the index in 2008 and 2011 are chosen as the dividing points of the price series. Dividing the dataset in such manner underlines the fact that the food crisis of 2008 is the first time period when the food or fuel issue got more of attention. These are the time dependent subsets of our dataset that will be examined in more detail:

- Food crisis period: 07/07/2008-28/02/2011, subset containing 140 observations
- Post food crisis period: 04/03/2011-22/2/2019, subset containing 418 observations

To better understand the role of biodiesel during the food crisis, we will apply all the diagnostic tests first on the whole time range and then the identical approaches will be applied on the food crisis period. If we observe interesting links, we will investigate how the evolved and whether they are present in recent years as well. The powerful feature of our dataset is the fact that it

Commodity	Average	SD	Skewness	Kurtosis	Min	Max
EU biodiesel	853,0	146,77	0,4010	-0,7315	589,8	1221,7
US biodiesel	1067,0	218,4416	0,8620	-0,3101	743,1	1658,3
US diesel	3,018	0,7253	0,1205	-0,8300	1,476	4,764
German diesel	0,5527	0,1320	0,1560	-0,7586	0,2593	0,8481
Palm oil	529,2	148,4958	0,2719	-0,2587	256,0	964,8
Rapeseed	349,3	80,8750	-0,5379	-0,8135	188,0	525,2
Soybeans	801,8	204,5589	0,002	-0,2047	384,4	1436,0
Sunflower seed	347,4	86,5951	-0,0925	1,0209	241,5	581,1
Cotton	57,16	16,5449	1,8749	6,51864	31,89	153,23

Table 4.1: Summary statistics of the series studied.

contains information about prices until now. We can therefore contribute to the discussion about biodiesel price interplay for a period of time that has not been studied until now, namely the year 2017 to 2019. The dataset utilized for the purpose of this thesis can be provided upon request.

Chapter 5

Methodology

5.1 Introduction

Our goal is to study the mutual interactions in the system of biodiesel and its feedstocks. It would indeed be nice and easy to study the price series using standard OLS regression, however as Granger & Newbold (1974) showed, there is an risk linked to this approach and the risk is called spurious regression. The word spurious refers to the fact that this kind of regression yields statistically significant coefficients and high R-squared, however in reality there is no economic connection between the studied variables whatsoever. For this study, an example of a regression that would turn out to be spurious could be regressing price of biodiesel on price of coca-cola.

The cause of spurious regression is the statistical concept known as non-stationarity. Non stationarity implies that the summary statistics of the series, such as mean or variance, are not constant over time. This feature may result in the phenomenon that several variables evolve in a similar manner for some time, hence OLS regression will bring significant results despite the absence of an actual economic relationship. However, in the end this non-stationarity is not a tragic issue. In fact, it can be beneficial for our research, because it turns out that if non-stationary variables can be arranged in an optimal manner, they form a stationary linear combination. Finding such a combination is of our interest, because its existence suggest that there is a long run equilibrium between the variables studied and allows for more detailed analysis. The specification of our analytic methods is the subject of the following text.

5.2 Unit root

Firstly, we need to choose the best auto-regressive model for each of the series in order to effectively study the presence of unit root in them. If a process contains a unit root, it means that number one is the root of its characteristic equation. As a consequence, such process is non-stationary and the risk of spurious regression is present.

The procedure of choosing the best AR model basically consist of determining the optimal number of lags that should be included in the model. After obtaining the best fitting auto-regressive models for each prices series with the use of Akaike Information criterion , these models are tested for unit root presence. Akaike information criterion is a method that compares models between each other and chooses the one that describes the actual evolution of variables the most accurately. For more details about how AIC chooses the best fitting model, please refer to Akaike (1981) . Note that there exist also other information criterions that might have different model preference, so to some extent, results of the analysis depends on the criterion choice.

If a series contain a unit root, then shocks have permanent effect on its values, as the series does not show any tendency to return to its mean. The unit root test used in this paper is the Augmented Dickey Fuller test. The null hypothesis of the Augmented Dickey Fuller test is that the series analyzed contains a unit root. The alternative is that the series is stationary. ADF test takes the equation

$$\Delta \boldsymbol{y_t} = \alpha + \beta t + \gamma \boldsymbol{y_{t-1}} + \delta_1 \Delta \boldsymbol{y_{t-1}} + ... + \delta_{p-1} \Delta \boldsymbol{y_{t-p+1}} + \epsilon_t \qquad (5.1)$$

And tests the null hypothesis

$$\boldsymbol{H_0} : \gamma = 0 \qquad (5.2)$$

α and βt are the intercept and time trend that can possibly be included in the testing. The idea behind the test is quite simple- if the lagged value of y has some effect on the change in y, it means that this process is always driven back to its mean and is hence stationary. If, on the other hand, $\gamma = 0$, lagged value of y has no effect on the change of y and therefore the process is non stationary, because there is no force pulling the process back to its equilibrium (mean). When this test is performed, following values are obtained: t-statistics, and p-value. The p-value can be interpreted as the likeliness that the process analyzed is non-stationary. Generally, p-value of less than 0,05 indicates that the null hypothesis can be rejected, because 5 % likeliness of unit root presence is small enough to be ignored. This hypothesis testing can also be performed by comparing our test statistic with the critical value from Dickey-Fuller table.

5.3 Cointegration

Following part of the study lays in analyzing whether the price series at our disposal are cointegrated. Mathematically, cointegration occurs when for the time series vector $X_t = (x_{1t}, ..., x_{nt})$ that contains I(1) series exists a vector $\beta = (\beta_1, ..., \beta_n)\prime$ such that the combination

$$\beta\prime X_t = \beta_1 x_{1t} + ... + \beta_n x_{nt} \tag{5.3}$$

is integrated of order zero, i.e. it is a stationary combination.

The concept of cointegration can be imagined by a general example. Suppose we have price series of two goods, whose evolution in time is visualized in a graph. If the distance between the two curves at each time point remains approximately the same over time, or there exists a constant that makes this happen, the conclusion is that the two series are cointegrated. The same concept can be implemented in the case of multiple series.

Variables are cointegrated only if the series share a so called common stochastic trend, so in that case there exists a linear combination of them where this trend cancels out and the combination is hence stationary. The constant vector β that creates a stationary linear combination is called cointegrating vector and it is our goal to find and analyze this vector.

As mentioned earlier, if a series contains a unit root, shocks have permanent effect on its values. Applying this idea on the method of cointegration, the fact that price series are cointegrated indicates that the series react to the same shocks. Identity in the shock reaction is what creates the system and causes the prices to co-move.

For the verification of cointegration, we use the so called Johansen cointegration test. The advantage of this test is that it can be applied on more than two cointegration relationships and therefore the whole system of biodiesel and its feedstocks can be studied. Moreover, Johansen test is actually connected to the ADF test in the sense that it examines the presence of unit root in a linear combination of variables and it provides estimates of the cointegrating vectors that brings stationarity to the system. This is done by the maximum likelihood estimation of the matrix $(\Pi - \boldsymbol{I})$ where Π is the cointegrating matrix from Equation (**4**)

In this thesis, both trace and maximum eigenvalue type of Johansen test will be used. Much more specific information about Johansen testing procedure can be found in Johansen & Johansen (1991).

Checking if the variables are cointegrated also helps to choose which ones of them should be included in the following Vector Error Correction model, because VECM only brings reliable results if the series inputted are cointegrated, as the model uses the long run equilibrium derived from Johansen test to compute the error correction terms, which describe the speed at which the variables return to their equilibrium (cointegration) after a shock caused them to deviate. This idea will be further developed in the following subsection.

The Johansen test is done successively for an increasing number of cointegrating relationships, meaning that the test starts with first null hypothesis as: "there are no cointegrating relationships in this system". If this hypothesis is rejected, following null hypothesis is "there is one cointegrating relationship in this system" et cetera, up to testing n-1 relationships, where n is the number of variables in the system.

5.4 VECM

The connection between VECM and cointegration is the following: cointegration finds the equilibrium relationship between the variables, and the deviations from this equilibrium are then studied using VECM, meaning that the error from last period is adjusted so the system is heading to the equilibrium defined by the cointegration relation. The powerful feature of VECM is that it enables studying both short and long term dynamics of the interaction between the series. Short run effects are observed due to the regression and Granger causality testing of first differences and long run effects are observed thanks to the adjustment parameter in the equilibrium relation. "Error correction" refers to the assumption of the model that there exist forces that drive the variables towards a common equilibrium. The goal of the model is to find and numerically express these forces.

In this thesis, we estimate the following Vector error correction model:

$$\Delta \boldsymbol{X_t} = \alpha + \beta t + \Pi \boldsymbol{X_{t-1}} + \Gamma_1 \Delta \boldsymbol{X_{t-1}} + ... + \Gamma_n \Delta \boldsymbol{X_{t-n}} + \epsilon_t \tag{5.4}$$

Where

- α and βt are the intercept and time trend that can possibly be included in the testing
- $\boldsymbol{X_t}$ is a time series vector of the commodities studied
- Π is the cointegration matrix, composed of the cointegrating vectors
- Γ is the matrix of coefficients on lagged differences of $\boldsymbol{X}$. The number $\boldsymbol{n}$ is chosen by Akaike Information criterion
- ϵ_t is the error term

Moreover, the cointegration matrix Π can be decomposed into matrices α and β, i.e. $\Pi = \alpha\beta\prime$ where

- α is the matrix of error-correction coefficients that adjust variables back to the equilibrium after a shock
- β is the matrix of cointegration coefficients that gives us the stationary combination of the variables

Our task will be to correctly estimate the VECM for the time periods where cointegration is found and then interpret the coefficients on α.

VECM and VARs in general have one big advantage- all variables that are included in them are treated as exogenous, meaning they are all given same role and importance in the model. This feature is very useful for our research, because our goal is to verify whether there is a biodiesel system formed by the fuel and the feedstocks of production. On the other hand, this advantage can be a liability at the same time. The issue is that VAR models are so called reduced form models. The word reduced implies that the evolution of one variable in the model is only justified by the evolution of the others, not allowing for the effects from outside. Such a restriction allows us to study the biodiesel market as a system, however it is likely that this system cannot cover the whole range of factors that influence food and fuel prices.

5.5 Granger causality

Granger causality testing is our tool to investigate short-run links between our variables. Broadly speaking, we say that variable x is Granger caused by the variable y if the value of x at time t, x_t can be, to some extent, explained by the previous values of y, i.e. $y_{t-1}, ..., y_{t-n}$. The evaluation of whether previous values of y help better prediction of x is done by comparison of an auto-regressive model of x with a regressive model that has both lagged values of x and y as independent variables. If the second model performs better at explaining the evolution of x, the conclusion is that there exist Granger causality running from y to x. The drawback of this method is that it only decides whether there is a causality between the two variables, but this information cannot unfortunately be expressed numerically. The possible extension is the impulse response function that studies how a shock to one price influences the evolution of the other prices.

Chapter 6

Results and discussion

This sections summarizes the results of our empirical analysis and draws possible conclusions from them. The results are presented progressively, according to the manner in which the methods were presented.

6.1 Augmented Dickey Fuller test

We run the ADF test. The number of lags included in the test has to be adjusted to be equal to the number of lags previously chosen by Akaike Information Criterion. AIC suggests 2 as the optimal number of lags. The results of unit root tests for logarithmic transformation of the series are provided in Table 6.1. Note that the results of ADF tests for feedstock prices are given only for the prices in EUR, but rest assured that the ADF tests for USD prices yielded similar results, from which identical conclusions can be drawn. The testing was also applied on the food crisis and post food crisis periods individually, arriving to the same conclusion. In order to be 100% sure about the nonstationarity of the data, we performed this test also with inclusion of intercept and time trend and the conclusions were always identical.

The p-value can be interpreted as the probability that price series studied has a unit root, hence is non-stationary. It can be seen that the p-value in all cases is relatively high (always bigger than 0.1) , which means that the null hypothesis of unit root presence cannot be rejected in any of the cases, not even at 10% of significance. This meets our expectations about the behavior of price series and indicates the necessity of differencing the series to make them stationary.

Then we apply the test on differenced prices in level. After looking at

Commodity	Dickey-Fuller	p-value
EU biodiesel	-2.4516	0.3871
US biodiesel	-1.9077	0.6174
German diesel	-2.0724	0.5476
US diesel	-2.06695	0.5500
Palm oil	-2.8892	0.2019
Rapeseed	-2.25	0.4725
Soybeans	-2.5953	0.3263
Sunflower seed	-2.9311	0.1842
Cotton	-3.0327	0.1412

Table 6.1: ADF default test results for log prices

Commodity	Dickey-Fuller	p-value
EU biodiesel	-7.86	< 0.01
US biodiesel	-7.6617	<0.01
German diesel	-8.791	< 0.01
US diesel	-7.2151	< 0.01
Palm oil	-8.3255	< 0.01
Rapeseed	-8.3547	< 0.01
Soybeans	-7.8313	< 0.01
Sunflower seed	-7.5269	< 0.01
Cotton	-7.956	< 0.01

Table 6.2: ADF test results for differenced log prices

the ADF test results, it is obvious that the differentiation really helps the series to become stationary,(at more than 1% significance) which in conclusion means that all the series are I(1). Results of ADF test for differenced data are summarized in Table 6.2

The fact that all the series have the same order of integration (order of integration tells us how many times a non-stationary price series needs to be differenced in order to become stationary) allows us to move to the next part of our study- cointegration.

6.2 Cointegration and VECM

We perform the cointegration testing successively, meaning we first test the whole dataset and then continue to each of the time periods previously mentioned. In all of the tests, we assume the presence of a linear time trend in the cointegration and we choose number of lags to 2, as suggested by Akaike Information Criterion. Unless otherwise specified, all the results displayed here are at 5% of statistical significance. For each VECM model, we verify its stability by checking the inverse root, always concluding that it lays within the unit circle.

First of all, we apply the Johansen cointegration test on the whole range of data at our disposal. The results of the tests confirm the assumption of very little connection between cotton and the other oils, which is logical given the fact that major part of cotton production is utilized rather in the textile industry. We therefore exclude cotton from further computations. Afterwards, the testing confirms cointegration for both markets, with one cointegrating relationship in each case. For EU, the equilibrium equation, normalized with respect to European biodiesel, is the following:

$$P_{EBIO} - \underset{(0,049)}{0,124} P_{GDIE} - \underset{(0,132)}{0,523} P_{RAPE} - \underset{(0,069)}{0,345} P_{PALM} + \underset{(0,074)}{0,499} P_{SOY} - \underset{(0,076)}{0,169} P_{SUN}$$

The numbers in parenthesis below the coefficients represent the standard errors of these estimates. We can immediately see that all the coefficients are statistically significant at 5%. These results seem to describe the EU biodiesel industry quite accurately: prices of biodiesel evince a co movement with the prices of its feedstocks. If we take into account the prices of rapeseed, palm oil and sunflower, the magnitude of the coefficients on these oils is to some extent proportional to their share on the biodiesel production. For example, if prices of rapeseed increase by 10%, this leads to the increase of EU biodiesel price by 10*0,523% i.e. about five percent in the long run, other things being equal. The same relationship hypothetically works the other way around as well. Little reminder from the Feedstocks section- in 2017, about one half of European feedstock for biodiesel was rapeseed. With feedstock being a main part of the cost of biodiesel, the equilibrium seems to go in hand with the coefficient on rapeseed being equal to circa one half.

Palm oil has a weaker relationship with biodiesel, yet still about 3,5% of the price change to one of the goods is transmitted to the other in the long run. The importance of sunflower seed is lower and the same can be said about German diesel, yet their effects are not negligible. The effect of the diesel price is also meaningful, given that this product is blended with biodiesel, hence it is logical that their prices will be positively related. Furthermore, biodiesel feedstock production and transportation requires the use of diesel, so that is

Commoditiy	ECT Estimate	SE	t-stat
EU biodiesel	-0,085	0,012	-6,996
German diesel	0,005	0,019	0,280
Rapeseed	-0,071	0,013	-5,493
Palm Oil	-0,041	0,018	-2,264
Soybeans	-0,099	0,021	-5,283
Sunflower seed	-0,043	0,018	-2,403

Table 6.3: Error correction terms for EU over the whole data range

another reason for this relationship. What on the other hand goes against our intuition, is the positive coefficient on the price of soybeans, suggesting the existence of a negative relationship between this good and EU biodiesel. There is a theoretical way to explain this- since soybeans are not largely produced in the EU, majority of this commodity is imported here. If the price of soybeans goes up, then biorefineries might in reaction turn to local feedstocks, so they would save on transportation cost, so in the long run they might decrease the price of their product. However, please note that this explanation is highly hypotetical. Further interpretation of these results will be possible when we estimate the VECM and see the speed of adjustment to this equilibrium. Overall, this equilibrium equation describes the biodiesel industry pretty accurately, suggesting that the prices of biodiesel are closely related to the prices of its feedstocks and to the prices of fossil diesel, that is being blended with biodiesel and is in addition largely utilized in the cultivation and transportation of biodiesel feedstocks. The related error correction terms are provided in the Table 6.3

The error correction terms tell us how fast a certain variable returns to the long run equilibrium after a shock to the other variables has occurred. A little reminder here- since we are working with weekly prices here, the low adjustment coefficients should not be interpreted as a very low speed, since a week is a considerably short time period, so the number must be looked at in the context of measurement rate. The most useful interpretation of these coefficients lays in comparing them between each other and between different time periods. Looking at the results for the whole time range, we can see that in the European market the returns to equilibrium are relatively fast. The interpretation is as follows- taking the example of EU biodiesel, after a shock to other prices occurs, EU biodiesel adjusts $8,85\%$ of the disequilibrium over the next time period, i.e. over a week in the case of our dataset. We can see that in this system, diesel prices do not adjust to the shocks to the other commodities, which is completely meaningful, given that diesel prices should not be influenced by the other commodities. Taking this information into account with the knowledge about the existence of an equilibrium in the biodiesel-diesel-vegetable oils system, the conclusion is that the agricultural commodities and biodiesel will to some extent follow the trend of diesel prices. In Europe, fastest returns to equilibrium are made by biodiesel, suggesting it is the most sensitive commodity for the shocks on vegetable oils and diesel prices. Fuel prices tend to change often, so we can say that this observation reflects the reality pretty well. Soybeans express even faster returns to equilibrium, but as we said before, the meaning of this information is uncertain. Here again, it can be said that for rapeseed and palm oil, these coefficients reflect their importance in the EU biodiesel market.

For the United States, after several different attempts we obtain this cointegration relationship:

$$P_{UBIO} - \underset{(0,121)}{0,081} P_{UDIE} + \underset{(0,289)}{0,227} P_{RAPE} - \underset{(0,162)}{0,639} P_{PALM} + \underset{(0,161)}{0,655} P_{SOY} - \underset{(0,163)}{0,607} P_{SUN}$$

We can see on the long run equilibrium that only palm oil, soybeans and sunflower seed have a statistically significant long run impact on the US biodiesel prices. The statistically insignificant coefficient of rapeseed prices goes against our previous finding about the relationship between the use of a feedstock and its impact on the equilibrium, nevertheless this might be due to the fact that both biodiesel and rapeseed production is much lower in US than in the EU. Palm oil and sunflower seed seem to have considerable positive effect on biodiesel prices, both of similar magnitude. Such effects are quite surprising, given that neither of the oils has a big importance in the biodiesel production. These coefficients might indicate that the US biodiesel market is determined by prices of vegetable oils in general, no matter what their importance on biodiesel production is. The mysterious coefficient on soybean prices is present in this equation as well. Table 6.4 contains information about adjustments to equilibrium in the US market. We can immediately see that are much slower than in the EU market, indicating that shocks in general tend to have longer lasting effects in the US equilibrium and the prices take some time to absorb the deviation. These numbers go in hand with the relative size of the two biodiesel markets, indicating that for the US the equilibrium will not be as much decisive for the price patterns as it will be in the EU.

Commodity	ECT Estimate	SE	t-stat
US biodiesel	-0,027	0,005	-5,545
US diesel	-0,0005	0,002	-0,194
Rapeseed	-0,0347	0,005	-6,199
Palm oil	-0,016	0,007	-2,314
Soybeans	-0,038	0,008	-4,616
Sunflower seed	-0,022	0,010	-2,201

Table 6.4: Error correction terms for US over the whole data range

Commoditiy	ECT Estimate	SE	t-stat
EU biodiesel	-0,164	0,048	-5,545
Rapeseed	-0,105	0,05	-2,1
Palm oil	-0,136	0,065	-2,201

Table 6.5: Error correction terms for EU during the food crisis

To better understand the position of biodiesel during the food crisis, we now investigate this period for a possibility to build a valid VECM, i.e one that has both statistically significant cointegrating vector and adjustment coefficients. By the method of trial and error, we discover this equilibrium in the EU market, with the error correction terms displayed in table 6.5

$$P_{EBIO} - \underset{(0,110)}{0,688} P_{RAPE} - \underset{(0,064)}{0,130} P_{PALM}$$

Looking at the results, we see that they change from the overall equilibrium, we can see that things change. Interplay between prices of biodiesel and rapeseed now becomes more evident, increasing by about 76% from the overall effect. For palm oil, the situation is the opposite, with the effect being about three times smaller in the food crisis period. Possible explanation might be that that as the EU support for biofuels expanded, this created stronger links between biodiesel and its main local feedstock. For the palm oil, since we talk about the food crisis, the cheapness of this oil might cause its stronger consumption on the food market, hence weakening the link with the biodiesel market. Another possible explanation is that palm oil was not largely consumed as a biodiesel during the food crisis, hence its strong position in the overall equilibrium might arise after this time period. We can also see that the speed of adjustment to the equilibrium increases significantly, being about

Commoditiy	ECT Estimate	SE	t-stat
Soybeans	-0,182	0,058	-3,137
US diesel	-0,030	0,014	-2,143

Table 6.6: Error correction terms for US during the food crisis

double of the overall speed for palm oil and EU biodiesel and by one half larger for rapeseed. This indicates that the food crisis might make the long run co movement between the prices more stable and more decisive for the prices of these commodities. Again, EU biodiesel adjusts the fastest to the disequilibrium, suggesting shocks to rapeseed and palm oil influence him more than the other way around. The increased speed of adjustment to the equilibrium gives us a crucial signal- during the food crisis, the link between food and fuel prices increases importantly, creating a more stable system where co movements are more evident.

For US market during the food crisis, we find one relationship that deserves attention- the equilibrium relationship between fossil diesel and soybeans, expressed in the following equation:

$$P_{SOY} - \underset{(0,22)}{0,882} P_{UDIE}$$

Revealing a very strong inter relation between their prices. Table 6.6 shows the error correction terms for this relationship. It is immediately obvious that soybeans do all the adjusting, while diesel is driving the equilibrium. We cannot draw too specific conclusions from this, but since long run relationship between neither soybeans and biodiesel or diesel and biodiesel came up in this region, we most likely cannot blame biodiesel to be the link between the increasing prices of diesel and soybeans in this time period. It more seems that this relationship exist due to the fact that fossil resources are one of the important costs of agricultural production, hence the prices of agricultural commodities will partly depend on diesel prices.

Finally, for the period 3, we discover a relationship that can be utilized to analyze the interconnections between solely the vegetable oil prices. The relation is between the major EU biodiesel feedstocks- palm oil and rapeseed. The equation is the following:

$$P_{RAPE} - \underset{(0,125)}{0,444} P_{PALM}$$

Commoditiy	ECT Estimate	SE	t-stat
Rapeseed	-0,145	0,033	-4,4
Palm oil	-0,107	0,047	-2,27

Table 6.7: Error correction terms for major feedstocks

Attached error correction terms are provided in Table 6.7. By including this equilibrium, we would like to point out that the long run relationship between only oil commodities is also important and will play a role in the biodiesel industry. We can see that the two oils tend to be close to each other, with about half of the change in one price being transmitted to the other. Looking at the error correction terms, we see that rapeseed is faster at returning to the equilibrium. Possible explanation might be the competitive relationship between the two commodities. As rapeseed oil is on average more expensive, he needs to quickly react to changes in palm oil prices in order to remain competitive. Palm oil, on the other hand, can due to its lower price allow to react slower to shocks on rapeseed prices.

6.3 Granger Causality

This section displays the results of Granger causality testing for both markets for the period between 2003 and 2019. Reults are written in the form $x \Rightarrow y$, which translates as " x Granger-causes y ". The p-values that are attached are related to the null hypothesis "x does not Granger cause y ". We include only the causalities that are related to diesel and biodiesel, but be aware that other causalities that concerned only the feedstocks were also revealed in the system. As can be seen on the p-values, all the causalities are at least of 10% significance. We look for the Granger causal pairs in the restricted VAR of our VECMs.

Tables 6.8-6.9 show the findings of Granger causal pairs for the period between 2003 and 2019.

Looking at the tables, we see that EU market has more of short run interactions between biodiesel and its feedstocks. What is again notable here is the importance of rapeseed in the interactions, being present in both directional causality with both EU and US biodiesel. Focusing on the US market, US biodiesel is Granger caused by three of its feedstocks while only Granger causing one, suggesting the dominance of the feedstocks over him in the short run.

Causality	p-value
US biodiesel ⇒ Rapeseed	0.10
Soybeans ⇒ US biodiesel	0.0258
Sunflower seed ⇒ US biodiesel	0.0475
Rapeseed ⇒ US biodiesel	0.005

Table 6.8: Granger causality pairs for United States

Causality	p-value
EU biodiesel ⇒ Sunflower seed	0.03
EU biodiesel ⇒ Rapeseed	0.10
German diesel ⇒ Soybeans	0.002
German diesel ⇒ Palm oil	0.026
Palm oil ⇒ EU biodiesel	0.0008
Rapeseed ⇒ EU biodiesel	0.067
Soybeans ⇒ EU biodiesel	0.003

Table 6.9: Granger causality pairs for Europe

EU biodiesel, on the other hand, is Granger caused by three of its feedstocks but also Granger causes two, suggesting his role is slightly stronger in terms of short run interactions. It is interesting that German diesel causes palm oil, suggesting its short run effect on this commodity may be due to the connection of European energy market with the palm oil market, which is a commodity largely consumed in Europe.

Finally, we perform impulse response analysis of the Granger causal pairs. For the EU market, we observe that rapeseed prices are about two times more reactive to the shocks to EU biodiesel than the other way around. Similar magnitude of shock transmission can be observed for impulses from biodiesel to responses in sunflower seed. This might suggest that in the short run, the price adjustments is moderated by biodiesel prices. Moreover, shocks to palm oil have bigger effects on EU biodiesel prices than rapeseed prices. This might indicate that the relationship between EU biodiesel and rapeseed is more stable in the short run than the one with palm oil, which is much more influenced by the prices on the global food market. The effects of EU biodiesel shocks on soy prices seem to be of weak nature.

For the US market, the short run interaction between rapeseed and biodiesel is similar to the one in the EU, so responses of rapeseed are more evident. Soybean has a weak short term impact on biodiesel prices. The effect of sunflower shocks on biodiesel prices can be compared to the small effects of rapeseed to the biodiesel prices.

Overall, this results are again interesting especially for the EU market in relation to the major feedstock, rapeseed. We have seen that in the long run, biodiesel adjusts to the equilibrium faster than rapeseed, hence having a weaker position in the system. In the short run, on the contrary, it seems that biodiesel prices seem to dominate over rapeseed prices, causing more of the short run fluctuation to this commodity.

Despite obtaining quite solid results, let us mention a few liabilities of our computations. Firstly, the outcomes for the EU market should be interpreted carefully, since the conditions of biodiesel production will vary for every member state, therefore we should not generalize them too much. This is also obvious when we take into account that we make our results with the use of prices of German diesel, but the prices of for example Estonian diesel prices will for sure be different especially in the short run. Despite an accurate description of soybean prices during the food crisis, our results have not been able to fully justify the position of soybean in the biodiesel market, so this issue should be a subject of further research. Another liability comes from the fact that we have converted the prices to the according currencies, nevertheless in the global food and fuel market the exchange rate fluctuations might have a significant effect on prices which we have not accounted for. Last but not least, we have assumed that our price series follow a linear trend, but previous studies suggested a quadratic trend is present in the food and fuel prices, hence different approach to the data analysis might come up with different conclusions.

Chapter 7

Conclusion

This thesis can be added to the list of papers that confirm both short and long run interconnections between biodiesel and its feedstocks. The key message that every reader should keep from this thesis concerns the EU market for biodiesel. Not only that this market, consisting of biodiesel and vegetable oils, forms a long run relationship that persists for over 16 years, but the magnitude of these relationships generally depends on the extent to which a certain oil is utilized in biodiesel production. Our results also show that price links got stronger during the food crisis of 2008. There is definitely a lesson to be learned from this, because this for sure has not been the last food crisis. In fact, with increasing population and decreasing resources of land and water, it is only a matter of time before another crisis comes. At such times, the policies that affect biofuels should become much more flexible then they are at the moment. Policies that support further generation of biofuels sound promising, but they will not completely solve the food or fuel issue, as they will still require land to be cultivated on. However, it seems that the intuitive thing to do would be to temporarily stop supporting biofuels when food prices are increasing rapidly.

Concerning areas for further research, we would have a few suggestions. Even though majority of biodiesel nowadays is made from vegetable oils, they are other feedstocks on the rise, namely animal fats and waste cooking oil. Neither of them have been studied for their relationship with food prices. For waste cooking oil, it would also be meaningful to try and improve the infrastructure for its collection, as this commodity rather than influencing food prices is a consequence of human nutrition. Another area for further research will for sure be the palm oil market. This oil will soon disappear from our tanks, and it will be interesting to see what happens to both prices of our fuels and to prices of this oil.

The long run close co movement of biodiesel and rapeseed prices confirms that big part of the large monotonic yellow fields we see every spring ends up in the tanks of our cars. One could say that whole concept does not seem too ecological in the end. It will definitely be interesting to examine how will new agricultural and environmental policies approach this concept and what will be the impact on prices of food and biodiesel. Planned European policies should weaken these links between biodiesel and edible oils by putting a limit on production of first generation of biofuels, but this thesis was written before the European elections in May 2019 and there is no econometric model that can accurately predict the impact of decisions of European voters on biodiesel and food prices. If countries will stay up to the promises they made in the Paris Climate Agreement, the new energetic strategies might bring unprecedented effects of energetic sector on prices of various goods. Biofuels will definitely play a role in this sector because unlike some animal species, diesel and gasoline engines are not endangered by extinction and will be used for many years to come. At this point, just as cars, the global economy runs on oil. More and more people start to dislike this fact and want changes, but also cannot imagine living without their beloved vehicle- life with a car is simply easier and more comfortable. Biofuels represent a path for them to reduce their dependency on fossil fuel, but unfortunately this is not necessarily happening now and therefore majority of drivers does not seem happy, because the blending only adds to the price of the fossil fuel they need. But when further generations of biofuels come to the market, this might change. In some more environmentally aware countries, a biofuel that is 100% scientifically proven to greatly reduce emissions might become a hit on the fuels market. With the help of skilled marketing experts, such kind of fuel might not even need financial support from the government to be profitable. At this moment when one can buy a vegan burger in McDonald's, it is surprising that one cannot easily buy a reliable ecological fuel at the pump. Oil companies intuitively seem to be the potential source of innovations in this area, but it seems they will rather sell what they have until one of these things happen: 1) the government bans it, 2) people stop buying it, 3) human population will die out and so will the market for oil. However, a good quailty biofuel can make the things different: 1) government does not have to ban anything but can rather effectively support an alternative that improves the situation, 2) people like this alternative, buy this fuel and hence invest in better future for themselves, 3) even the oil companies are satisified, because if demand for fossil fuels decreases moderately they can prepare themselves for restructuralization of their business and keep a strong position in the new energetic sector.

A little final note on the climate change. It is now clear that global warming is not a concept that was made up by environmental activists. Actually, everyone that is reading this text is living in the era of changing climate and the impacts will be seen with every year to come. Rather than being worried or depressed about this, humans should take advantage of their well known ability to overcome problems by their intelligence. If this intelligence is well used, further implementation of biofuels in our energy sector might lead to better future of everyone.

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