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BACHELOR THESIS

Genetically Modified Biofuels in the Context of Central Europe

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

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Abstract

Biofuels have been in the center of focus for many years. They are believed to be the solution to rising fossil fuel demand. This work links together cellulose based biofuels and genetical engineering. Biofuels consumption and production are encouraged all over the world. On the other hand genetical engineering faces harsh legislative obstacles. Our work examines the influence of genetically modified (GM) corn on corn for silage yields, which can be used to produce cellulose based ethanol. Results of our model state that if 85% of corn sown area in the Czech Republic (CZ) was dedicated to GM corn, the yields of corn for silage would increase to 150%. Main drawback of our analysis is that estimates suffer from large uncertainty. Based on discovered significant positive effect, the work recommends liberalization of rigorous European Union (EU) legislation concerning GM crops. The results of this work can indicate further focus of biofuel industry as well as development in genetical engineering.

JEL Classification	Q16, Q42, C23
Keywords	biofuels, cellulose based ethanol, GM crops, GM corn

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Abstrakt

Biopaliva jsou středem pozornosti po mnoho let. Věří se, že by mohla být řešením problému vzrůstající poptávky po fosilních palivech. Tato práce spojuje biopaliva a genové inženýrství. Spotřeba i výroba biopaliv je podporována po celém světě, avšak genové inženýrství čelí nepříjemným legislativním překážkám. Tato práce zkoumá vliv pěstování GM kukuřice na celkové výnosy kukuřice na siláž, která může být použita pro výrobu etanolu na bázi celulózy. Výsledky naší práce říkají, že pokud by se 85 % osevní plochy kukuřice přenechalo GM kukuřici, zvýšily by se výnosy kukuřice na siláž na 150 %. Nedostatkem práce je vysoká míra nejistoty v odhadech. Na základě statisticky významného pozitivního efektu GM kukuřice na výnosy tato práce doporučuje uvolnění evropské legislativy týkající se GM plodin. Výsledky této práce mohou být ukazatelem pro další zaměření průmyslu biopaliv a vývoje v genovém inženýrství.

Klasifikace JEL Q16, Q42, C23
Klíčová slova biopaliva, ethanol na bázi celulózy, GM plodiny, GM kukuřice

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Acronyms

B-P	Breusch-Pagan Lagrange Multiplier
Bt	Bacillus thuringiensis
CCP	Climate Change Package
CEEC	Central and Eastern Europe countries
CZ	Czech Republic
df	degrees of freedom
EEA	European Environment Agency
EFSA	European Food and Safety Association
EU	European Union
FAPRI	Food and Agricultural Policy Research Institute
FE	Fixed Effect
FGLS	Feasible Generalised Least Squares
GHG	Greenhouse Gas
GLS	Generalised Least Squares
GM	genetically modified
ha	hectares
HT	Herbicide-tolerant
ILUC	Indirect land-use change
OLS	Ordinary Least Squares
RE	Random Effect
RED	Renewable Energy Directive
t	tones
USA	United States of America

Bachelor Thesis Proposal

Author	Pavla Bláhová
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Proposed topic	Genetically Modified Biofuels in the Context of Central Europe

Topic characteristics Genetically modified plants have changed DNA thanks to genetic engineering. Genetic manipulation is used to strengthen desired qualities or introduce new features. In the European Union each GMO has to be approved by the European Commission before being introduced to either farmers or consumers. Bio fuels can be divided into two groups: first and second generation. Second generation covers bio fuels produced from cellulosic materials. First generation bio fuels are produced from oil crops, cereal crops, and sugar crops. Established technology is used to produce this type of bio fuels. Hydrotreating is a technical process of production of "Renewable Diesel Fuel" from vegetable oils. There are concerns about sustainability of biofuels made from food crops. In my bachelor thesis, I will investigate the impact of introducing genetically modified plants on competitiveness of biofuels in Central Europe.

Literature Based primarily on works by David Zilberman et al. dealing with bioeconomy, GMO, and biofuels.

Steven Sexton and David Zilberman,: "How Agricultural Biotechnology Boosts Food Supply and Accomodates Biofuels." *NBER Working Papers 16699*, National Bureau of Economic Research, 2011

Chapter 1

Introduction

Biofuels, especially the advanced ones, are supported and encouraged all over the world. Favorable legislation was created to increase biofuel production as well as consumption. Partial replacement of fossil fuels by biofuels is an important step in achieving the targets set by EU. Genetical engineering could be an important element in increasing biofuel production. Unlike biofuels, genetical engineering faces many legislative obstacles and stirs up heated discussions. GM crops demand less herbicides and pesticides and therefore they are associated with lower nature damage. The opponents of GM technology argue that GM crops can lower the biodiversity and that the impact of altered genes on animals and humans is still unknown.

The main objective of this thesis is to connect the biofuels literature with genetical modifications literature by considering the potential of GM for increasing the efficiency of biofuels production. This is done for one particular case through analyzing the effect of GM corn adoption on overall yields of corn for silage. Cellulose based biofuels can be produced from the corn for silage or corn stover and therefore increased yields also increase the biofuel production. GM technology is also associated with lower costs of planting and could result in lower cost of biofuel production.

The work is divided into two main parts: Literature review and Analytical part. In the Literature review, we focus on the background of biofuel industry and genetical engineering. In the Section 2.1 reader can find description of policy development in EU, of the production of biofuels, and of biofuel perspectives in Central and East Europe. In the Section 2.2 description of genetical engineering, GM crops in Central and East Europe, and commercialized GM biofuel crops can be found. The aim of the Analytical Part is to examine the effect of GM corn adoption on overall corn for silage yields. Our findings are summarized in the Conclusion.

Chapter 2

Literature review and background of biofuels and genetical engineering

2.1 Biofuels

By the term biofuels we understand solid biomass, various biogases and liquid fuels. The further text is related to liquid biofuels, specifically ethanol and biodiesel. In this section we will describe current political situation regarding biofuels in Central Europe. A detailed description of liquid biofuels and their production process follows. The section Policy development in EU is based on Janda et al. (2012), EU Biofuels Annual 2012 (USDA Foreign Agricultural Service), (Flach et al., 2012) and data from Eurostat. Section describing biofuel production is based on Boundy et al. (2011), Balat (2011), and FAPRI (2013).

2.1.1 Policy development in EU

Throughout the world, the great interest in biofuels was generated over the periods of oil crises in the 1970s. High oil prices fueled interest in replacing fossil fuels. The process of developing biofuels continued during the 1980s and 1990s. The significant increase in biofuel production in the new millennium was driven by government policies and public interest in ecology. The reasons for governmental support may differ extensively among the countries, but they may be summarized into four categories: energy independence, environmental sustainability, support of agriculture in the sense of enlarging demand, and support of agriculture in the sense of bringing benefits to rural areas. This governmental support should provide a ground for growth in sustainable living standards and overall long term sustainable economic growth.

As far as the biofuels policy legislative is concerned, Biofuels Directive (2003/30), the EU Energy and Climate Change Package (CCP) and the Fuel Quality Directive (2009/30) have main impact on biofuels in EU. Biofuels Directive set a goal of achieving 2% share of biofuels in transport by 2005 and 5.75% by 2010. European Commission admits that both targets were very ambitious. Data taken from Eurostat[1] show us the results of EU biofuels supporting policies. In 2005 the share of biofuels in transport reached only 1% and for 2010 4, 7%. The only countries that met the 5.75% target of biofuels share in transport in 2010 were Poland, Slovakia, and Sweden with 5.9%, 7.8%, and 7.7% respectively.

Part of the EU CCP is Renewable Energy Directive (RED) which established the "20/20/20" goals. These goals should be achieved by 2020 and consist of:

- 20% reduction in green house gas emissions (compared to 1990)
- 20% improvement in energy efficiency (compared to 2020 forecasts)
- 20% share of renewable energy in gross final energy consumption
- 10% share of renewable energy in fuel consumption of transport

In the year 2010, the last year for which comprehensive data are available, Greenhouse Gas (GHG) emissions show promising results. GHG emissions are steadily declining and reached level of 85% of 1990s values in 2010. There has been a decline of 6 percentage points in between 2000 and 2010[2]. The European Environment Agency (EEA) estimate for the year 2011 is 82.5% of 1990s values (EEA, 2012). This shows again the declining trend of GHG emissions in the EU.

The share of renewable energy in gross final consumption reached 12.5% in 2010. The highest consumption of renewable energy traditionally occurs in Scandinavia countries. Norway and Sweden attained admirable 61.1% and 47.9%, respectively. Countries of Central Europe (CZ, Poland, Slovakia) rank towards the bottom with values slightly under 10%[3].

The EU share of renewable energy in fuel consumption of transport grew from 1.9% in 2006 to 4.7% in 2010. Distribution among states is more even.

[1] Eurostat: Share of renewable energy in fuel consumption of transport, "tsdcc340", downloaded: March 12, 2013

[2] Eurostat: Total Greenhouse Gas Emissions (in CO_2 equivalent) indexed to 1990, "tsdcc100", downloaded: March 12, 2013

[3] Eurostat: Share of renewable energy in gross final energy consumption, "tsdcc110", downloaded: March 12, 2013

Best result in 2010 reported Slovakia and Sweden with 7.8% and 7.7% respectively. Both Czech Republic - 4.6% and Poland - 5.9% can be found in the upper part of EU countries[4].

Fuel Quality Directive together with technical standards issued by the European Committee for Standardization regulates the properties of biofuels. Both fuel additives and their amount that can be blended into fossil fuels are regulated.

On the January 24, 2013, EU expressed the support of sustainable advanced biofuels through publishing communication - COM(2013). Motivation behind COM(2013) is that "Transport in Europe is 94% dependent on oil, 84% of it being imported." European Commission (2013), page 1. Key part of this EU support of biofuels is emphasized on sustainable advanced biofuels. As described in the following section Production of biofuels, food crop based biofuels are not included among sustainable advanced biofuels in the EU.

2.1.2 Production of biofuels

EU is the biggest importer of both ethanol and biodiesel. Consumption of biofuels in EU is expected to increase more than production, therefore EU will remain net importer of biofuels (FAPRI, 2013).

Ethanol, which is the main biofuel in US, continues to play only minor role in the EU, as compared to biodiesel. In blends, ethanol increases octane and improves emissions quality of gasoline. Demand for ethanol is also increased by its antiknock properties. Major drawback of ethanol is its hygroscopic nature which may cause corrosion of the engine. In order to reduce the corrosive character of ethanol, an anhydrous ethanol can be produced. However, anhydrous ethanol has additional drawbacks, such as higher production cost, it is hard to produce and handle, and it has worse life cycle emission profile (Breaux and Acharya (2011)). Most common blend of ethanol is E10 combining 10% of ethanol with 90% of fossil fuel. Other ratios are also possible, but blends with ethanol share higher than 30% require special engine modifications. Blends with arbitrary share of ethanol can be used in flex-fuel engines which are common in Brazil, but not in the EU.

In 2011 biodiesel accounted for 70% of the EU biofuel market on the volume basis (Flach et al., 2012). Biodiesel is produced and consumed in EU on

[4]Eurostat: Share of renewable energy in fuel consumption of transport, "tsdcc340", downloaded: March 12, 2013

much higher scale than ethanol. For comparison, in 2012 EU produced 1617 million gallons of ethanol and 3191 million gallons of biodiesel (FAPRI, 2013). Biodiesel has similar properties as mineral diesel (derived form fossil fuels) and therefore it is used in various blends. These blends are called B5, B10 or B20 where numbers represent the percentage of biodiesel in the blend.

Production process

Traditionally, biofuels are produced from food crops such as corn, oilseeds and sugarcane. The most frequent types of biofuels are ethanol and biodiesel. Ethanol is produced from crops rich in sugars (sugar beet, sugar cane) or starch (cereals, especially corn). The technological process is very simple and well known. Firstly, starch has to be converted into sugars. This is achieved by adding enzymes to the milled crops. Secondly, sugars from the crops are fermented into ethanol. The last step in the production process is distillation. The most commonly used feedstock for ethanol production in EU in 2012 was sugar beet followed with a large distance by wheat and corn (FAPRI, 2013).

Biodiesel can be produced from vegetable oil (rapeseed, soybean) or animal feedstock. Biodiesel is produced using the process of transesterification. In practice it means mixing the biomass with methanol and sodium hydroxide. The chemical reaction produces fatty acid methyl, also known as biodiesel. Rapeseed is the main source of biodiesel in EU. The volume of rapeseed oil used for biofuels in 2012 was almost six times greater than the volume of soybean oil and sunflower oil combined. This is in contrast with the United States of America (USA) where soybean oil accounts for almost a half of total biodiesel production (FAPRI, 2013).

The technological process of making biofuels from food crops is the most mature one. Researchers focus on new sources of biofuels production, therefore no significant improvement is expected in the technological process of making biofuels from food crops with exception of utilizing food crops residuals such as corn stover.

Despite being the most mature process in the field of biofuel production, food crops based biofuels are available only in limited volumes due to land competition. Many opponents of the food crop based biofuels argue that producing biofuels steers up food prices and forces farmers to expand area under cultivation. The relation between biofuel and food prices is a subject of a rapidly developing literature, for example see Kristoufek et al. (2012, 2013). The most recent survey of this literature is provided by Serra and Zilberman (2013).

Expanding land under cultivation is associated with costs connected to land conversion and risk of loss in biodiversity. Converting idle land into agricultural land is a costly process from the point of view of combating greenhouse gas emissions. Such greenhouse gas emission related costs are caused by Indirect land-use change (ILUC) and significantly decrease the benefits of biofuels (Lapola et al., 2010). The cost of first generation biofuels is also increased by the necessity of expensive inputs such as land, water, fertilizers, pesticides etc. (Ziolkovska and Simon, 2011).

Food crop based biofuels are not expected to provide full replacement for petroleum (Antizar-Ladislao and Turrion-Gomez, 2008). There are studies emphasizing the benefits of biofuels and thanks to various government encouragements (subsidies, targets and mandates), the production of food crop based biofuels is plentiful all over the world. Hill et al. (2006) studied ethanol production from corn grain and biodiesel production from soybean. Their results were that ethanol yields 25% energy surplus and biodiesel yields 93% energy surplus. Early studies like the one conducted by Tan et al.(2004) supported the idea of biofuels reducing the CO_2 emissions. On the example of coconut biodiesel in the Philippine automotive transport sector they came to the conclusion that biodiesel can yield reductions in net CO_2 emissions compared to petroleum diesel.

On the contrary, the introduction of ILUC concept initiated a debate on what should be included in the computations of GHG emissions savings. ILUC is associated with transferring the ecological costs of producing biofuels outside of the place where biofuels are consumed. The key assumption of the ILUC debate is that the demand for agricultural land increases with the rising demand for biofuels. For example, Lapola et al. (2010) studied biofuel production from sugarcane and involved deforestation in Brazil. Results of their analysis show that ILUC offsets the GHG emissions savings from biofuels. In some cases using biofuels instead of fossil fuels creates carbon debt that may last for 250 years (Lapola et al., 2010).

To reduce ILUC effect, EU decided on further regulation of the biofuel production. The new EU policy proposal should encourage further replacement of food crop based biofuels by more advanced technologies, like cellulose based biofuels (Nelsen, 2012).

Advanced technological processes allow biofuels to be made from cellulosic feedstock (Antizar-Ladislao and Turrion-Gomez, 2008). In practice this usually means production of ethanol from cellulose waste. Under the term cellulose waste, agricultural and wood residues, organic waste, and energy crops (switchgrass, rye, bamboo, and many others) are hidden. Despite ongoing research in this field, cellulosic based biofuels are burdened with high production costs and commercial production is at its early stage. Introducing cellulosic based biofuels is linked with development of new infrastructure. Developments in the field of enzymes, pre-treatment, and fermentation are crucial for the cost and energy efficiency of cellulosic based biofuels.

In analytical part of this work, we explore the possibilities of improving the yields of corn for silage by genetical engineering. Therefore we include a brief description of ethanol production from corn. Ethanol can be produced from corn in two ways: from grain or from the whole plant. The corn grain is rich in starches and it is suitable for the food crop based ethanol production. However, improvement in technology allows us to employ the whole plant, not only grain. Corn for silage is cellulosic feedstock and therefore it could be used for cellulosic based ethanol production as described by Oleskowicz-Popiel et al. (2008). If the corn is grown for grain and not intended for grain based biofuels, we can still use stover (a residue after the grain has been harvested) for cellulose based biofuel production.

Although the Bloomberg press release by Isola (2013) states that cellulosic based biofuels will not be commercially available at least until 2016, there is newly launched commercial cellulosic based biofuel plant in Crescentino (Italy), in December 2012. There also exist pilot plants like DuPont pilot cellulosic ethanol refinery (Heggenstaller, 2012) close to the city of Nevada in Iowa (USA), which produces ethanol solely from corn stover.

A study conducted by Zhuang et al. (2013) compares the production of biofuels from corn, switchgrass, and Miscanthus. Switchgrass is a type of grass naturally occurring in North America. Miscanthus is a perennial grass native to Africa and southern Asia. The sterile hybrid between Miscanthus sinensis and Miscanthus sacchariflorus, Miscanthus giganteus, has been trialed as a biofuel in Europe since the early 1980s. It is known for its high yield of biomass (up to 25 t/ha) and desirable properties for cellulose based biofuel production. Production of ethanol from corn is examined in both cases of food crop based biofuel from grain and cellulose based biofuel from stover. The results of Zhuang et al. (2013) show Miscantus as the most suitable for cellulose based biofuels. Corn placed as the second best option. Switchgrass turned out to be the least suitable (Zhuang et al., 2013). Altough not being the most suitable, corn has the advantage that it can be grown for grain and the stover can be used for biofuel production.

There are even more advanced methods than producing biofuels from cellulose waste. Rather than focusing on improvements in the technological production, some researchers focus on the improvements in the feedstock itself. The goal is not only producing sustainable energy, but also achieving overall CO_2 reduction. Current research in the field of improving feedstock focuses on algae. This large group of autotrophic organism could be used to ethanol, biodiesel and even jet fuel production. The problem is the same as with ligno-cellulosic based biofuels. The technical procedures are in early stage of development and they are not suitable for commercial use (Shirvani et al., 2011).

2.1.3 Biofuel perspectives in Central and East Europe

The amount of biofuels that can be produced does not depend solely on available conversion technology. It is strongly influenced by the amount of land used for feedstock growth and improvements in the feedstock, particularly yields. This section focuses on the land possibilities in Central and Eastern Europe countries (CEEC) and how it can influence the biofuel production, because CEEC are considered to be the only European region suitable for large scale expansion of biofuels production.

Kondili and Kaldellis (2007) divide the whole process of producing and utilising biofuels in five separable stages: feedstock production, biofuel production, blending, distribution, and final consumption. To fulfill their potential in biofuel production, individual CEEC do not have to realize all stages of biofuel production themselves, although it would bring them doubtless advantage.

The first stage of feedstock production has to be realized especially in the countries with vast areas of land available for biofuel production. Fischer et al. (2010) in their analysis of future land use estimated that in 2030 the land area potentially available for growing biofuel feedstock is 41.5 - 45 million hecrates in CEEC[5]. Ukraine alone accounts for 21.8 - 22.6 million hectares (ha). For comparison, the EU15[6] countries plus Switzerland and Norway have only 2.7 - 8.1 million hectares of agricultural land potentially available for growing biofuel

[5]Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Slovenia, Slovakia, Bulgaria, Romania, Ukraine

[6]Austria, Belgium, Germany, Denmark, Spain, Finland, France, Greece, Ireland, Italy, the Netherlands, Portugal, Sweden, United Kingdom

feedstock by 2030. Emphasis in the calculations of Fischer et al. (2010) was given to sustainable agricultural practices, “food first” paradigm, and nature conservation. Authors suggest that even more land could be freed for biofuel feedstock if the yields increase and less land would be needed for maintaining food security.

The production process of biofuels itself, blending of biofuels into fossil fuels, distribution, and final consumption of biofuels poses technological as well as policy demands. The details of production process are described in Section 2.1.2 and current EU policies regarding biofuels are summarized in Subsection 2.1.1. Mainly two countries from CEEC are well equipped and have experience with biofuel production on large scale: Czech Republic and Poland (Kondili and Kaldellis, 2007). In other countries of CEEC many investment opportunities are available into small-scale biofuel production units. Kondili et al. (2007) further states that the distribution of biofuels is done by companies not specialized in biofuel transport. The final consumption does not face sizable barriers. It is encouraged by favorable EU legislation and biofuels can be easily used by current technology.

Although the potential of CEEC countries is considerably higher than potential of EU15 countries, its realization depends greatly on whether or not competitive conversion technologies will be locally available. Required investments are high and their realization questionable. Consumption on the other hand does not raise major problems as biofuels can be used in today’s cars without major adjustments.

2.2 Genetical modifications

Preceding section described the possibilities in expanding land under cultivation. This section focuses on how the feedstock itself can be altered to increase the amount of produced biofuels. In addition to further mentioned studies, this section is based on Qaim (2009), Ervin et al. (2010), and James (2011). Parts about genetical modification and plant breeding in general are based on Hansson and Joelsson (2012) and Yunbi (2010).

Plant breeding is a conventional technique used to preserve and improve desirable genetic characteristic. It has been around helping the human race to ensure food security for thousands of years. Early stages of breeding were done merely through artificial selection (using only plants with desirable traits for further breeding). Breeding developed as a science at the beginning of the 20th century. New breeding techniques like hybridization, tissue culture, induced mutation, and increasing the number of chromosomes by chemicals and radiation attained significant success. Ondrej and Drobnik (2002) see genetical modification as inevitable development in plant breeding.

Herbert Boyer and Stanley Cohen laid the fundamentals of modern genetical engineering in 1973. GM crop is a plant into which one or several genes has been inserted through the process called genetical engineering. This modification ensures desirable traits of crop. Plants designed this way do not differ much from conventionally bred ones. Thanks to sharply growing research, GM crops experienced commercial application in the mid 1990s. Genetically engineered crops quickly gained popularity all over the globe, reaching 160 million hectares of sown area in 2010 James (2011). However, this enthusiasm is not shared in Europe. The distrust is obvious from the Table 2.1. The only European country, where GM crops occupy significant area, is Spain. Other European countries rank at the very bottom or they are not present at all due to restrictive government policies.

The country differences in the legislative approach to GM crops are described in the section GM crops in the world and in Central Europe. The section Commercialized GM biofuel crops gives a brief review of currently available genetic modifications of crops that are being used for biofuel production. This section gives also a summary of main advantages and drawbacks of such GM crops.

Table 2.1: Global area of GM crops in 2011 by country

Rank	Country	Area (million hectares**)	GM crop
1	USA*	69.0	Corn, soybean, cotton, canola, sugarbeet, alfalfa, papaya, squash
2	Brazil*	30.3	Soybean, corn, cotton
3	Argentina*	23.7	Soybean, corn, cotton
4	India*	10.6	Cotton
5	Canada*	10.4	Canola, corn, soybean, sugarbeet
6	China*	3.9	Cotton, papaya, poplar, tomato, sweet pepper
7	Paraguay*	2.8	Soybean
8	Pakistan*	2.6	Cotton
9	South Africa*	2.3	Corn, soybean, cotton
10	Uruguay*	1.3	Soybean, corn
11	Bolivia*	0.9	Soybean
12	Australia*	0.7	Cotton, canola
13	Philippines*	0.6	Corn
14	Myanmar*	0.3	Cotton
15	Burkina Faso*	0.3	Cotton
16	Mexiko*	0.2	Cotton, soybean
17	Spain*	0.1	Corn
18	Colombia	<0.1	Cotton
19	Chile	<0.1	Corn, soybean, canola
20	Honduras	<0.1	Corn
21	Portugal	<0.1	Corn
22	Czech Republic	<0.1	Corn
23	Poland	<0.1	Corn
24	Egypt	<0.1	Corn
25	Slovakia	<0.1	Corn
26	Romania	<0.1	Corn
27	Sweden	<0.1	Potato
28	Costa Rica	<0.1	Cotton, soybean
29	Germany	<0.1	Potato
	Total	160.0	

* 17 GM mega-countries growing 50,000 hectares, or more, of GM crops
** Rounded off to the nearest hundred thousand
Source: Adapted from "Global Status of Commercialized Biotech/GM Crops: Brief 43-2011", by C. James, 2011, ISAAA Brief No. 43. ISAAA: Ithaca, NY

2.2.1 GM crops in Central and East Europe

Referring again to the Table 2.1 above, one has to think. Why is there such inequality in GM crops adoption? The arable land in EU27 accounts for approximately 102 Mha, however only on 0.1 Mha GM crops are grown (Park et al., 2011). First of all, we have to investigate under which conditions farmers adopt new technology, in this case genetically modified seeds, and to what extend. Sexton and Zilberman (2011b) summarized studies regarding these conditions. Three main factors influencing adoption of GM crops are economic conditions, biophysical conditions, and regulatory conditions. Under economic conditions we understand output and input prices. Because these prices change each year, some farmers may decide to newly adopt GM crops or switch back to regular seeds. Biophysical conditions are unique to each location.In general, areas with high pest pressure profit more from adoption of GM crops, therefore these areas are more likely to adopt such technology. Regulatory conditions differ extensively among states.

EU is very cautious when it comes to genetically modified organism in general. GM crops are not exemption. EU approaches the whole topic with intent of GM and non-GM crops coexistence (Wesseler, 2012). Legislation issued by EU simply tries to avoid compete replacement of non-GM crops by their GM alternative. Such replacement could cause irreversible changes in species composition and loss in biodiversity. The following summary of EU legislation is based on information published by European Food and Safety Association (EFSA) and Plan and Van den Eede (2010).

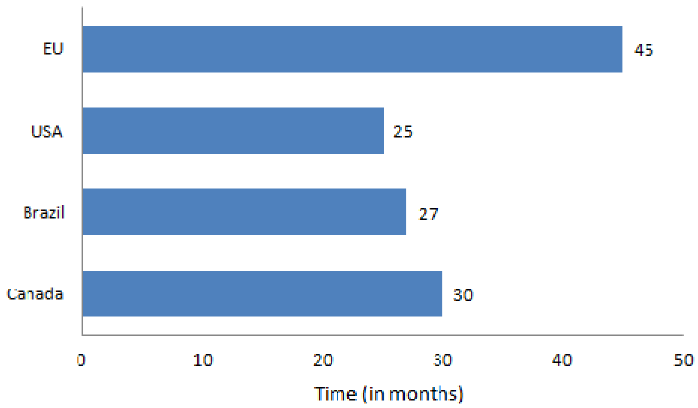
Ukraine does not allow the introduction of genetically modified crops into the nature at all.

Genetically modified organisms are defined in the EU legislation as "organisms in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination". Unlike in USA, European legislation judges each GM plant based on the technique by which it was developed. The EU legislation also provides list of techniques which are considered to result in genetic modification and techniques which are not considered to result in genetic modification. This list does not cover all techniques available. Interestingly enough, some scientists argue that the definition of GM plant provided by EU is very vague and open to speculations.

There are two main EU legal instruments regarding genetically modified organisms: Directive on the deliberate release into the environment of Genetically Modified Organisms (2001/18/EC) and Regulation on Genetically Modified Food and Feed (EC No 1829/2003). Both are important for the biofuel industry if it should produce biofuels from GM crops.

Directive 2001/18/EC regulates deliberate release of GM organisms into the environment. Its primary goal is to protect human health and the environment. It sets rules for both experimental release (field trials) and commercial release through placing GM seeds on the market. The experimental release for field trials is purely in the competence of national authorities, therefore authorisation does not apply for other Member States of EU. Regulations regarding commercial release of GM organisms are in competence of EFSA, yet national authorities have important task in issuing an opinion. The decision of EFSA applies to the whole EU, however each member state can exploit the safe guard clause and place a provisionally ban on an approved GM organism. The whole process is very complicated and lengthy. On the graph borrowed from EuropaBio we can see that EU has the longest average approval time - 45 months.

Figure 2.1: Average time required for a GM product approval in the EU, USA, Brazil, and Canada



Source: EuropaBio, 2011, "Approvals of GMOs in the European Union", p.11

2.2.2 Commercialized GM biofuel crops

The ground elements of genetical engineering were laid in the mid 1980s. Developed in the USA, the first GM crops introduced for commercial use were insect resistant crops or so called Bacillus thuringiensis (Bt) crops. The insect resistance was achieved through inserting a gene of soil bacterium called Bacillus thuringiensis (hence Bt crops) into the crop. When the larvae of lepidoptera, diptera or coleoptera feed on the crop, they ingest the so called Cry protein. This protein causes irreversible intestine damage and unavoidable death by starvation of the insect. Bt technology can be used as a substitute for chemical insecticides but Bt crops are not entirely immune to pests. The resistance is $90-95\%$ (Ondrej, Drobnik; 2002) . The remaining pests are eliminated through the use of pesticides. The use of Bt crops significantly decreases the number of pesticide sprays. Ondrej and Drobnik (2002) used the example of Bt cotton. Regular cotton needs on average 5 - 12 sprays during one vegetation process, the Bt cotton reduces the number to maximum 3 sprays during one vegetation. The main Bt crop that is used for biofuel production on a large scale is Bt corn.

In the CZ the only GM crop permitted by the law is corn. The only allowed genetical modification of the corn is inserted gene MON810 that results in Bt modification.

Bt crops do not have direct influence on the crop yield. This was expressed by Zilberman et al. (2004) in a damage control framework. It shows, that potential yield (assuming no insect damage at all) is not directly effected by the use of Bt crops. Effected is only the effective crop yield, as Bt reduces the losses due to insect damage. Positive yield effect of Bt corn was confirmed by Nolan and Santos (2012). They investigated the effect of introducing GM traits on corn for grain yield in the USA in the years 1997 - 2009. The study shows that introducing Bt trait has significant positive effect on corn for grain yields. Furthermore, the results of their study suggest that GM crops may have led to 1,4 - 1,5 times higher increase in corn for grain yields when compared to traditional crop breeding.

Although not first commercialized, Herbicide-tolerant (HT) is the dominant GM technology. First HT crops introduced to the commercial use were HT corn (1997) and HT canola (1999). Adoption of HT crops has steadily grown since their introduction to the market. In 2008 HT crops accounted for 63% of total GM crop area (James, 2011). Herbicides are the most widely used pesticides. They shelter the crops against weeds and allow for higher yields. HT crops allow for lower use of especially preemergent herbicides (applied to the soil before occurrence of particular pests). Herbicides to which the crops are tolerant are used on the leaf and their content is optimized according to particular pest. Planting HT crops allows substitution of classical herbicides to faster degrading herbicides and an overall reduction of herbicide use. Findings by Nolan and Santos (2012) confirm the expectations about yield neutrality of HT crops. Two main advantages of HT crops are the cost reduction and reduction in herbicide sprays. Main HT crops that can be used for biofuel production are soybean, wheat, rapeseed, and sugarbeet.

It is possible to insert both Bt and HT traits in one plant. Introducing more than one trait into one crop is referred to as stacking and results into stacked variety. Nolan and Santos (2012) compared the gain in yields associated with stacked varieties. The result is that stacked varieties have increased crop yield but the study suggests it is in the sense of concave additivity rather than linear additivity. Nolan and Santos (2012) dealt with three GM traits: Corn borer, Root worm and herbicide tolerance. Their finding is that combining the three GM traits is not statistically different from combining Root worm and HT traits. The study also suggests that some interactions between individual traits may be present.

Bt crops and HT crops are made using method called first-generation GM technology. In the process of first-generation modification predominantly only single genes are being altered. There are considerable benefits associated with adoption of the first-generation GM crops. Ervin et al. (2010), specifies these benefits: lower expenditures on damage control, reduced crop losses and associated lower risk of yield variability, improved worker safety, and greater flexibility in farm management. Location, crop, and time have big impact on the magnitude of these effects. Some magnitudes of these benefits have been empirically estimated. Quaim(2009) provides us with summary of these very heterogenous estimates. Sexton and Zilberman confirmed the positive effect of adopting GM crops. "First generation GM crops permit the intensification of agriculture, which effectively frees land for production of biofuels, or at least diminishes the demand for new cropland induced by rising food and fuel needs." Sexton and Zilberman (2011a), page 19. In the conclusion they mention an important topic. The possibility to expand agriculture output without expanding area under cultivation. The possibility of significantly increasing crop yields could soften the controversy of food crops being used to produce biofuels. Growing the GM crops to produce biofuels does not involve the human health argument against GM crops and therefore could be publicly easier accepted. The decrease in production cost of biofuels could be weakened by legislation on GM animal feed. Selling production residuals as animal feed is a considerable reduction of biofuel production costs.

GM technologies commercially available at the present time represent small fraction of the GM crop potential. Future prospects for the first generation GM technologies lay in fungal, bacterial and virus resistance, drought tolerance, and salt tolerance (Hansson and Joelsson, 2012). Also possibilities of second generation GM technologies are under research. These genetical modifications aim on product quality improvements for nutrition and industrial purposes. Examples of second-generation GM crops are Golden Rice, which is enhanced with provitamin A, high amylose maize, and oilseeds with different fatty acids profiles. As far as our knowledge goes, no genetical modification is available or under research to improve desirable properties exclusively for the biofuel production. Third generation GM technologies are also under research. They are designed to produce either pharmaceutical or industrial products. Vaccines, enzymes, and bio degradable plastic can be produced in this way (Hansson and Joelsson, 2012). Third-generation GM crops have not been relevant to biofuel industry yet.

Chapter 3

Analytical part

3.1 Motivation

Analytical part of this work should answer the question whether the use of genetically modified corn with inserted MON810 gene increases the overall corn biomass yield in the production and environmental conditions of the Central Europe, in particular in the Czech Republic. Answering such question brings us closer to exploring the possibilities of biofuels in the context of Central Europe since the GM modified biomass is a very natural promissing feedstock for the production of advanced biofuels.

The current status of GM crops in Europe is very different from that in the USA, where many GM crops are grown (corn, soybean, cotton etc.). Nolan and Santos (2012) investigated the effect of genetical modifications on corn for grain yields in the USA using data from experimental field trials. Results of their analysis suggest that yield of GM corn is $1.4 - 1.5$ times higher than the yield of regular corn. Another important outcome of their analysis is that Bt corn is associated with increase in corn yields but HT corn seems to be yield neutral. This has an important implication for our analysis since the only GM corn hybrids grown in the Czech Republic have inserted MON810 gene resulting in Bt modification. In our analysis we would like to confirm the assumption of positive effect of Bt corn on overall corn for silage yields in the CZ. An important difference between Nolan and Santos (2012) and our research is that while Nolan and Santos (2012) examine influence of GM on grain yield, we are interested in overall biomass yield. While the results of Nolan and Santos (2012) are therefore directly relevant for first generation conventional biofuels produced from corn grain, our results are directly relevant for second generation advanced biofuels production.

The potential of GM crops in EU is decreased by conservative legislation which results in little effort put into GM research. Therefore, in Europe we do not have field trial data comparable with the USA ones. However not having data on field trials is not an unbeatable obstacle. Another paper investigating the yield gains from GM corn for grain in USA by Xu et al. (2010) analyzed the effect of GM corn on corn for grain yields using weather conditions as control variables. They came to similar conclusion as Nolan and Santos (2012). We therefore base our analysis on controlling for weather conditions.

Both above mentioned studies investigate the effect of GM modifications on corn for grain yields. We based our decision to use corn for silage in our analysis on the following grounds.

In the CZ, regulations on further manipulation with GM product are rigorous and result in GM corn being grown almost exclusively for silage. If certain GM crop is allowed to be grown in the CZ, it does not mean that all further manipulation is allowed (animal feed, human consumption etc.). Therefore investigating the effect of GM corn on corn for grain yields in CZ is not feasible.

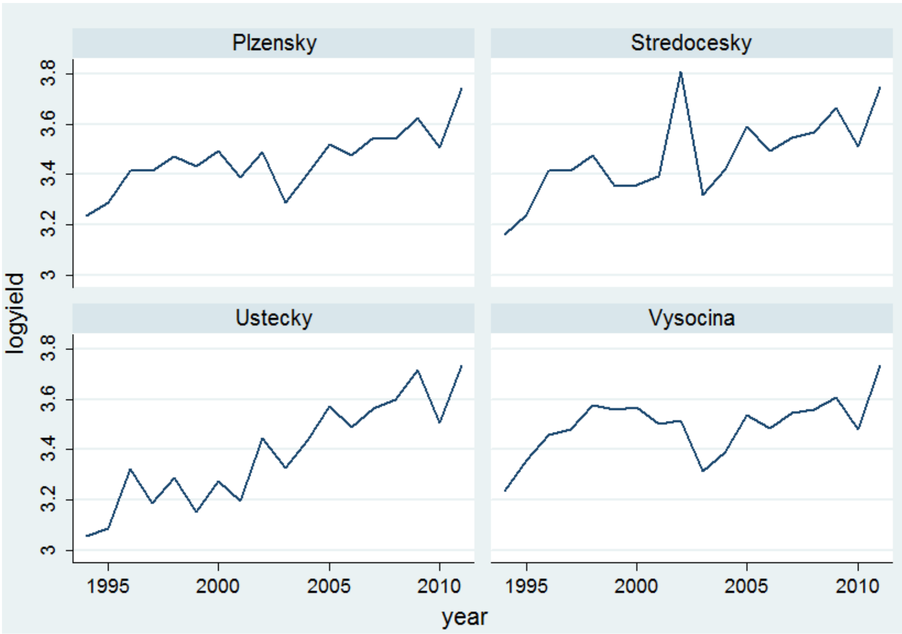
In the CZ if produced from corn, ethanol is produced through the food crop based procedure. With the technological improvements in the cellulose based biofuels production, ethanol could be produced also from the corn for silage or corn stover. Refineries producing cellulose based ethanol are already available in Crescentino (Italy) on commercial scale and in a number of pilot plans in USA and Europe, like for example pilot refinery of DuPont in Nevada, Iowa (USA). This DuPont refinery focuses its production process on corn stover. Stover is the part of plant remaining after harvesting the grain. As opposed to stover, silage is made from the whole plant. Increased yields can reduce the cost of production, boost the produced volume of ethanol, and the land occupied by crops dedicated for ethanol production would be smaller.

3.2 Data

To answer our question, we used the data on the overall yield of corn for silage, share of GM corn sown area, average temperature, and average rainfall in the Czech Republic for the years 1994 through 2011 for each of the 14 regions in the Czech Republic. There are no observations missing, therefore we have balanced panel data. The data set is available on request.

Data on corn for silage were obtained through personal communication with the Czech Statistical Office. They involve data on sown area in ha and crop in tones (t). Yield was calculated for each year and region by dividing crop by sown area and therefore it is measured in t/ha. For statistical purposes, corn for silage is weighted right after harvesting without letting the crop dry (Czech Statistical Office, 2012). The whole plant is used for silage and therefore the whole plants are being weighted. Yield therefore measures how many tones of corn biomass has grown on 1 hectare of sown area. The highest yield in our dataset is 45.2 t/ha, the lowest one is 18.9 t/ha. Mean value of corn yield in our data is 33 t/ha.

Figure 3.1: Logarithm of corn yield in specific regions through the years 1994 - 2011



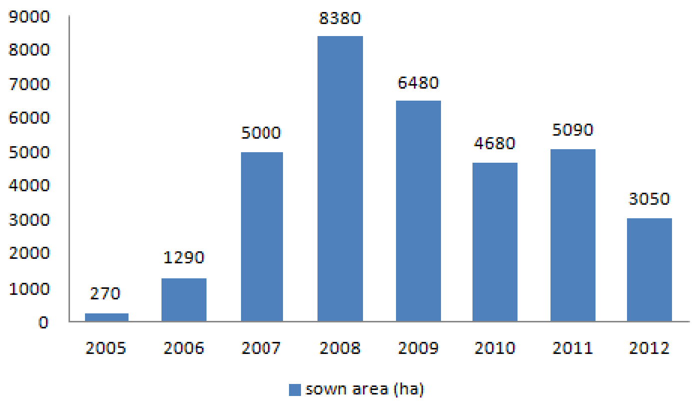
Source: Author's computations based on data from the Czech Statistical Office.

As we can see in Figure 3.1, logarithm of yield shows clear upward trend. The trend is visible in all 14 regions of CZ. For illustration, we decided to include figures of Stredocesky, Plzensky, and Vysocina regions because of the clear trend and large sown area of corn. Ustecky region is included because of the large share of GM corn.

Data on the sown area of GM corn measured in ha were obtained through the communication with The Ministry of the Environment of the Czech Republic, which is legally obliged to collect information on all GM crops grown in the

Czech Republic. Original data were arranged according to individual farms and listed by the date of notification. These data had to be rearranged to the form suitable for our analysis - according to year and region. Sown area of GM corn was divided by total sown area of corn to get the share of land dedicated to GM corn. The maximum share was achieved in Ustecky region in 2009 where GM corn accounted for 21% of corn sown area. The median is slightly under 2%. GM corn has been grown in the Czech Republic since 2005, until then the share of GM corn sown area is 0.

Figure 3.2: Sown area of GM corn in CZ through the years 2005 - 2012



Source: Based on data from Ministry of the Environment of the Czech Republic.

In the Figure 3.2 we can see that the adoption of GM corn in CZ has increased sharply since 2005 to its peak of 8380 ha in 2008. During the next years the sown area has steadily declined to 3035 ha in 2012. Both sharp rise and steady decline are not primarily caused by legislation. There has been a sudden increase in cornborer occurrence. Farmers were not technically equipped to protect crops through conventional techniques, therefore they started growing GM corn. Till 2008 farmers had time to acquire required technic for the use of conventional methods of protection and new conventional techniques emerged.

For the growth of corn, two weather factors are crucial: temperature and rainfall. In our analysis, both temperature and rainfall are used in monthly manner. On average, corn in the Czech Republic is sown in May and harvested in August (Vrzal et al, 1995). Therefore, average regional temperature and rainfall for the months May, June, July, and August were taken. Temperature is measured in $^{\circ}C$, rainfall in millimeters ($1mm = 1l/m^2$). Data on both temperature and rainfall were downloaded from the web site of the Czech Hydrometeorological Institute.

The yield of corn is influenced by many other factors besides temperature and rainfall. Two main factors important for corn yield that are not included in our analysis due to data availability are altitude and amount of fertilizers used (Vrzal et al, 1995). Omitting these two factors should not invalidate our analysis. Potential bias resulting from possible correlation of fertilizers use and GM seeds use is analyzed in Section 3.6. Altitude can be considered as individual heterogenity. We are using methods that treat individual heterogenity of regions. As an approximation of technology development, we include time trend in our model.

3.3 Model

Based on available data and reviewed literature, following model was used to investigate the effect of share of overall corn sown area dedicated to GM corn on corn yields. Variables used in the model are following: logarithm of corn yield ($logyield$), share of GM corn on overall corn sown area multiplied by 100 ($GMshare100$) for interpretation purposes, average rainfall in the months May, June, July, and August ($rmay$, $rjune$, $rjuly$, and $raug$, respectively), average temperature in corresponding months ($tmay$, $tjune$, $tjuly$, and $taug$, respectively), and time trend ($year$). Time-periods are denoted with subscript t and regions with subscript i. We have data available for the years 1994 - 2011, therefore $t = 1, 2, ...18$. The CZ consists of 14 regions, therefore $i = 1, 2, ...14$.

$$\begin{aligned} logyield_{it} &= \beta_0 + \beta_1 GMshare100_{it} + \beta_2 rmay_{it} + \beta_3 rjune_{it} + \beta_4 rjuly_{it} + \\ &+ \beta_5 raug_{it} + \beta_6 tmay_{it} + \beta_7 tjune_{it} + \beta_8 tjuly_{it} + \\ &+ \beta_9 taug_{it} + \beta_{10} year_{it} + u_{it} \qquad (3.1) \end{aligned}$$

For the error term u_{it} following equation holds where μ_i denotes the cross-section specific components (also called time-invariant) and ν_{it} is remainder effect.

$$u_{it} = \mu_i + \nu_{it} \qquad (3.2)$$

The time-invariant error includes regional specifics that do not change over time. Such regional specifics include land fertility, altitude, and other.

This model was estimated by Pooled Ordinary Least Squares (OLS), Fixed Effect (FE), and Random Effect (RE) procedures. The exact methodology is described in the section Methodology.

3.3.1 Expectations

The crucial expectation is a positive effect of GM corn on corn yields which leads us to positive β_1. Significance of this effect is difficult to forecast. The share of GM corn in the Czech Republic is small.

Technology plays an important role in agriculture. Each year new fertilizers, chemical treatments, and improved techniques like irrigation systems are developed. As mentioned above, technological progress can be expressed in time trend therefore we anticipate β_{10} to be positive and significant.

Both rainfall and temperature will be jointly significant over included months. Significance in each month is difficult to forecast, but in general these two factors are important for corn, especially in May and June (Vrzal et al, 1995).

Further expectation about our model is present heterogenity. The fertility rate in each region is different as well as altitude and other climatical conditions.

3.4 Methodology

The model was estimated by standard panel data procedures - OLS, FE, and RE using software Stata/IC 12.0. In this section the details of all three econometrical methods are described. The description of Haussman test and Breusch-Pagan test for heterogenity is also present. Description of methodology is based on Baltagi (2008) and Woolridge (2009).

3.4.1 Pooled Ordinary least squares

The main benefit of pooled OLS is increased sample size thanks to adding time dimension. To obtain Pooled OLS we need to have random sample at two or more points in time. Advantage of Pooled OLS is that we have bigger data set and can estimate the change in relationships among variables over time. Unfortunately, we have no use for this advantage when exploring the influence of GM corn share on overall corn yield. Pooled OLS estimators are unable to control for individual heterogenity. Not controlling for individual heterogenity results in biased estimators. Following FE and RE procedures are able to control for individual heterogenity.

3.4.2 Fixed effect

Fixed effect model treats time-invariant μ_i as fixed parameter and estimates it. Consider following model where k is the number of independent variables, $i = 1, 2, ...N$, $t = 1, 2, ...T$, μ_i is the time-invariant, and ν_{it} is remainder effect.

$$y_{it} = \beta_0 + \beta_1 x_{it1} + ... + \beta_k x_{itk} + \mu_i + \nu_{it} \tag{3.3}$$

Fixed effect procedure involves time demeaning, which averages Equation 3.3 and subtracts it from the original equation. We get:

$$y_{it} - \bar{y}_{it} = \beta_1(x_{it1} - \bar{x}_{i1}) + ... + \beta_k(x_{itk} - \bar{x}_{ik}) + \mu_i - \bar{\mu}_i + \nu_{it} - \bar{\nu}_i \tag{3.4}$$

The time-invariant μ_i is constant over time and therefore it is swept away from the equation. The same holds for the constant term β_0. The resulting equation is:

$$\ddot{y}_{it} = \beta_1 \ddot{x}_{it1} + ... + \beta_k \ddot{x}_{itk} + \ddot{\nu}_{it} \tag{3.5}$$

If we look back at our model, the above mentioned variables represent deviation from time average for the region i.

FE estimation accounts for individual heterogenity but can not estimate the effect of such time-invariant variables. This does not interfere with our goal as we are not trying to estimate these effects. Using FE estimation provides us with consistent estimates under standard assumptions.

3.4.3 Random effect

If we think of μ_i in our model as random, we can use FE no longer as it would be inefficient. Simple OLS procedure could be used while we believe μ_i to be uncorrelated with explanatory variables, but simple OLS ignores serial correlation in the error term. If we assume μ_i to be uncorrelated with each explanatory variable in all time periods and also uncorrelated with all ν_{it}s, we can use RE model. The RE model is specified as follows:

$$y_{it} = \beta_0 + \beta_1 x_{it1} + ... + \beta_k x_{itk} + u_{it} \tag{3.6}$$

where $u_{it} = \mu_{it} + \nu_{it}$ is called composite error term.

RE model is estimated using quasi-demeaned data. We obtain quasi-demeaned data in a following way. Firstly, we assume:

$$Corr(u_{it}, u_{is}) = \frac{\sigma_\mu^2}{\sigma_\mu^2 + \sigma_\nu^2} \tag{3.7}$$

for all $t \neq s$, where $\sigma_\mu^2 = Var(\mu_i)$ and $\sigma_\nu^2 = Var(\nu_{it})$.

Secondly, we subtract from the original model averaged equation multiplied by λ, where

$$\lambda = 1 - \left(\frac{\sigma_\nu^2}{\sigma_\nu^2 + T\sigma_\mu^2}\right)^{1/2} \tag{3.8}$$

This leads us to the following equation which contains quasi-demeaned data.

$$\begin{aligned} y_{it} - \lambda\bar{y}_{it} &= \beta_0(1-\lambda) + \beta_1(x_{it1} - \lambda\bar{x}_{i1}) + ... + \beta_k(x_{itk} - \lambda\bar{x}_{ik}) + \\ &+ (u_{it} - \lambda\bar{u}_i) \end{aligned} \tag{3.9}$$

By putting our data through Generalised Least Squares (GLS) procedure we obtained uncorrelated errors. In practice we need to obtain an estimate of λ as it is composed of theoretical variances. Such estimate of λ is obtained according to Equation 3.8 using Pooled OLS procedure. Thus RE model is estimated using Feasible Generalised Least Squares (FGLS) procedure.

RE estimators are consistent and approximately normally distributed with valid standard statistical inference under standard assumptions. Estimating model through RE allows for variables constant over time. Crucial assumption for the consistency of RE is μ_i being uncorrelated with explanatory variables. Under such assumptions RE estimators are more efficient than FE assumptions.

Without knowing exact value of λ we can never achieve RE estimators to be unbiased.

3.4.4 Tests

To decide between our three models we need to perform tests. To decide whether or not we can use pooled OLS we will use Breusch-Pagan Lagrange Multiplier (B-P) test. Haussman test will be used to decide between FE model and RE model.

After estimating the model by RE we can run the Lagrange multiplier test developed by Breusch and Pagan (1980). We exploit B-P test when we want to test for heterogenity. B-P test is specified by

$$H_0 : Var(\mu_i) = 0 \tag{3.10}$$

$$H_1 : Var(\mu_i) \neq 0 \tag{3.11}$$

Under H_0 the Pooled OLS model is preferred as variation in μ_i is zero and we therefore found no evidence for heterogenity. Under H_1 we assume heterogenity is present. RE procedure gives us better estimates of true coefficients because it accounts for individual heterogenity.

Haussman test is based on exploring the relationship between μ_i and explanatory variables x_{it}. The hypothesises are:

$$H_0 : cov(\mu_i, x_{it}) = 0 \tag{3.12}$$

$$H_1 : cov(\mu_i, x_{it}) \neq 0 \tag{3.13}$$

Under H_0 there is no correlation between μ_i and x_{it}. Therefore both FE and RE are consistent. Using the RE procedure gives us asymptotically more efficient estimates. Under H_1 RE estimates are no longer consistent due to violation of model assumptions. In conclusion RE estimates are preferred under H_0 and FE estimates are preferred under H_1.

3.5 Empirical results

First of all, we checked the normality of data by running the Jarque-Bera test for normality in residuals. The Jarque-Bera test rejects the null hypothesis of normally distributed residuals (p-value zero to the third decimal place). However, after visual inspection of the histogram of residuals and dependent variable *logyield* we concluded that the distributions are close enough to normal distribution and we will treat our data as approximately normally distributed. This means that standard statistical inference is valid. The histogram of dependent variable *logyield* and the histogram of residuals can be found in Appendix A.

We ran the regressions according to the methodology described in the section above. Results of each regression can be found in Appendix B. At last, tests described in Section 3.4 were used to determine most suitable model for our analysis.

3.5.1 Model estimates

As we look at the results of all three models, we can see they have many common features. Both OLS model and FE model have high R^2 – 0.49(p-value equal to zero to the fourth decimal place) and 0.57 (p-value again equal to zero to the fourth decimal place), respectively. RE model has χ^2 equal 287.35 which gives us p-value very close to 0. These numbers show us that dependent variable is well explained by our model. If we look further on similarities in our three models, we can see that the signs of all coefficients across our three models are the same. Difference between our models is in the significance level of coefficients.

Share of GM crops has in all three models positive sign – 0.004 in the OLS model and 0.006 in both FE and RE models. The signs of $GMshare100$ coefficients do not differ, but their significance levels do. In the OLS estimation the coefficient of $GMshare100$ is not significant at even 10% significance level. In fact the exact p-value is 0.18 (t-statistic= 1.36). In both FE and RE models the coefficient is significant at 5% level (t-statistics are 2.0 and 1.97, respectively). The quantitative interpretation of our FE and RE models is that if we dedicate 1 more percentage point of corn sown area to GM corn we increase the overall corn yield by 0.6% t/ha.

Technological progress contained in our regression in the time trend has also positive effect on corn yields. Moreover, the coefficient is 0.015 with significance level 1% in all three models (t-statistic is around 10 in all three models). This shows us the importance of technological improvements in agriculture.

The key interest in our analysis lies on the coefficient of $GMshare100$ while both rainfall and temperature are control variables. However, to fully describe the results of our three models, we include also description of estimated rainfall and temperature coefficients.

Average rainfalls in each months are jointly significant in all three models with p-value very close to 0. Such strong significance confirms the importance of positive influence of rainfalls to the corn yields. All three models tell us that rainfall is important especially in the months June and July. The coefficients by the months May and August are zero to the third decimal point and their significance is also negligible. If we try to run the regressions without the variables $rmay$ and $raug$ the significance of $GMshare100$ decreases. Therefore we decided to keep both $rmay$ and $raug$ in our regressions.

The strong influence of temperature on corn yield is confirmed by strong joint significance of average monthly temperatures. The p-value of joint significance test in all three models is close to 0 (F-statistics are 4.8 with 241 degrees of freedom (df) in OLS model, 10.9 with df 228 in FE model, and $\chi^2_4 = 34.5$ in RE model). Average temperature in May has positive sign and it is significant at 1% level in all three models (t-statistics are around 3.5). Temperature in June has negative sign but it is the least significant temperature term in all three models. Temperatures in July and August have also negative sign and are significant at 1% level (t-statistics range from 3.4 to 4.6) in the FE and RE models.

Results concerning rainfall and temperature are in line with agronomic literature. May is important as the corn germinates and growth sets off. Corn needs both moisture and warm temperature. Rainfall is not significant in May as the corn uses especially moisture from defrosted soil. The intensive growth takes place in the months June and July. Both rainfall and temperature are crucial in this stage. Corn needs sufficient amount of rainfall and suitable temperature to create biomass. Corn is very demanding on rainfall. Interestingly enough temperature has negative effect. The optimum temperature for vegetative growth is around 20 °C. Higher temperatures slow down the creation of biomass and therefore lead to lower yields of corn for silage. The temperature is important during the whole growth of corn. Harvesting of corn for silage proceed in CZ on average during August. Rainfall is no longer crucial for corn because the biomass has already been created (Vrzal et al, 1995).

3.5.2 Testing the models

We have three models with comparable results. It is still necessary to decide which model suits our data best. It is possible to compare our three models based on tests described in Subsection 3.4.4.

After running the RE procedure we can exploit B-P test for heterogenity. If we look at the results of B-P test, we can see that the $H_0 : Var(\mu_i) = 0$ is strongly rejected with p-value very close to 0 (χ^2 equal to 72.44). There is strong sign of heterogenity in our model which is in line with our expectations. This tells us that the RE model is preferred to Pooled OLS.

To compare the FE and RE models we used the Haussman specification test. The result of the test yields sign of correlation in the error term. We reject H_0 at 3% significance level (test statistic 19.94). In this case Haussman test tells us to prefer FE model over RE model.

All of our three models have given us similar estimates, but based on the B-P test for heterogenity and Haussman specification test we can point out the most relevant model. B-P test tells us that heterogenity is present in our data. This rules out Pooled OLS model and leaves us with FE and RE models that are able to cope with heterogenity. Both these models give us almost the same estimates. If we still want to find the most relevant model we look at Haussman test for specification which tells us to prefer FE model over RE. Therefore, the model which fits our data best is the FE model.

3.6 Discussion

In this section we compare our expectations with relationships among variables as estimated by FE model which showed up to suit our data best. The table with results and significance of each estimate can be found in Appendix B and the description of results in Subsection 3.5.1. For easier comparison of our expectations with relationships found in the model we include estimated equation. Variables *rmay* and *raug* do not appear in the equation because their estimated coefficients were 0 to third decimal place.

$$\begin{aligned} logyield_{it} &= -26.809 + 0.006\ GMshare100_{it} + 0.001\ rjune_{it} + 0.001\ rjuly_{it} + \\ &+ 0.023\ tmay_{it} - 0.011\ tjune_{it} - 0.021\ tjuly_{it} + 0.031\ taug_{it} + \\ &+ 0.015\ year_{it} + u_{it} \end{aligned} \tag{3.14}$$

Our first and crucial expectation regarding our data was present heterogenity. After testing the models and choosing the FE model as best fitting our data, we can say that our expectation was confirmed. Important implication is that there are regional specifics influencing the yield.

Our expectation regarding the question whether or not the GM corn increases the corn yields was affirmed by our model. The estimated coefficient is not only positive but also significant on 5% level. To recall the interpretation from Subsection 3.5.1, we remind that this estimate tells us that if we dedicate 1 more percentage point of corn sown area to GM corn we increase the overall corn yield by 0.6% t/ha. Consequent paragraphs show us that this is a considerably high effect.

As mentioned in Section 3.2 describing our data, we have no data available on the amount of fertilizers used. Because the use of fertilizers and the use of GM seeds might be correlated, we have to consult the potential bias. There are three options:

$$corr(fertilizers, GM) > 0 \tag{3.15}$$

$$corr(fertilizers, GM) < 0 \tag{3.16}$$

$$corr(fertilizers, GM) = 0 \tag{3.17}$$

Above equations show positive correlation, negative correlation, and no correlation between use of fertilizers and use of GM seeds, respectively.

If the first option is true and farmers tend to use more fertilizers when they adopt GM seeds, our estimates would be biased upward. Negative correlation between use of fertilizers and use of GM seeds represents the situation when farmers use less fertilizers after they adopt GM seeds. Such relationship would result in downward bias of our estimates. Based on the findings of Zilberman et al. (2004), GM seeds do not influence the yield directly and therefore the same amount of fertilizers should be used whether the conventional or GM seeds are used. There are many reasons for correlation that stem from the cause of adopting GM seeds. We can speculate that if the farmer purchases more expensive GM seeds then he is less likely to buy costly fertilizers. Other speculation could be that if the use of GM seeds reduces the use of herbicides and pesticides the application of fertilizers is more likely.

Nevertheless, we believe that zero correlation between use of fertilizers and use of GM seeds is most likely and therefore our estimates are unbiased.

The largest share of GM corn was achieved in 2009 in Ustecky region where GM corn accounted for 21% of corn sown area. For various reasons GM corn cannot be adopted on 100% scale. Lets consider the 21% as a boundary for GM corn adoption in CZ. The average share of corn sown area dedicated to GM corn in 2011 is 2.6%. By FE model we estimate that if 18.4 more percentage points of corn sown area were dedicated to GM corn, an increase of 10.6% would be achieved in crop yield. The 95% confidence interval for our estimate is $(0.2, 21.2)$. Such broad confidence interval can be explained by heterogenity of the regions. Nevertheless the important information contained in this prediction is the positive sign of the effect. The average yield in 2011 was 42 t/ha. Using the 10.6% as the best prediction, the adoption of GM corn to 21% of corn sown area would increase the yield to 46.5 t/ha. Such yield overcomes the maximum yield of our data set by more than 1 t/ha.

The true maximum achievable share of GM corn is much higher than 21%. In 2009 the share of GM corn in the USA was 85% (GMO Compass, 2010). After consulting the maximum share of GM corn in CZ with the company Pioneer, which sells genetically modified seeds in CZ, we came to the conclusion that 85% is an reachable share. After including 85% to our computations we gain an increase of nearly 50% with 95% confidence interval equal to $(7.6, 94.8)$. The confidence interval is again very broad due to regional heterogenity. Using 50% as the best estimate we reach the yield of 63 t/ha.

Time trend in our estimated model has positive coefficient which is significant at 1% level. Both these results are in line with our expectations.

To evaluate our expectations toward temperature and rainfall, we have to take two steps. Firstly, we have to look at the joint significance over included months. Both temperature and rainfall are strongly significant which is in line with our expectations. Secondly, we have to look at individual months. When it comes to rainfall, only June and July are left in our equation. This does not confirm our expectation about the first two months being crucial for corn growth. On the other hand, temperature is significant in all four months (at 1% in May, July and August, at 10% in June).

The model confirmed majority of our expectations and all of our important expectations (heterogenity, effect of GM corn on corn yields, time trend). It even gave us more significant results on the effect of GM corn on overall corn yields than we expected.

Chapter 4

Conclusion

In this work, we wanted to shed some light on the possibilities arising from genetical engineering with respect to biofuel industry. The production of biofuels is plentiful all over the world and genetical engineering could significantly increase its potential. The commercially available technique to produce biofuels at present time is conventional food crop based production. Two previous studies conducted by Nolan and Santos (2012) and Xu et al. (2010) in the USA confirmed the positive effect of genetical engineering on corn for grain yields.

Advanced techniques of biofuel production are not yet commercially available, but quick improvements are expected in the field of cellulose based biofuels. Such biofuels can be made from any cellulose biomass. EU sees the future of biofuel industry in advanced production techniques, therefore we focused on the potentials of GM crops with respect to cellulose based biofuels production.

In the CZ the GM corn is grown predominantly as corn for silage. In our analysis we focused on the question, whether the use of GM corn statistically significantly increases the yield of corn for silage in the environmental conditions of the Czech Republic. We builded upon previously mentioned studies examining corn for grain yields. We used weather conditions – monthly temperature and monthly rainfall – as control variables and we included the time trend to account for technological development.

We estimated our model by Pooled OLS, FE, and RE. Results obtained from all these three specifications were qualitatively quite similar, which shows good robustness of our results. Results estimated by all three models were in line with our expectations of positive effect of GM modifications on corn for silage yields. FE model showed up as best fitting our data while it helps to treat regional heterogenity that is present in our data set. Estimates from the FE model suggest that if GM corn was adopted on 21% (which is the maximum adoption rate in the CZ achieved in Ustecky region) of corn sown area the yield would increase by 10.6% which gives us average yield of 46.5 t/ha. Our model is limited by large uncertainty which is reflected by broad confidence interval: $(0.2\%, 21.2\%)$.

If we extend the adoption rate on 85% of corn sown area the uncertainty increases. The confidence interval widens on $(7.6\%, 94.8\%)$ with the best prediction being nearly 50%. Such increase gives us average yield of 63 t/ha. These results are in agreement with both studies from the USA, although they cannot be directly compared as those studies examine corn for grain yields.

The contribution of this work stems not only from unique data set but also from innovative connection of two topics: biofuel industry and genetical engineering. Biofuel production is supported and plentiful all over the world, but genetical engineering faces legislative obstacles. Our work supports the idea of softened legislation toward GM crops. As genetical engineering can positively influence the yield of crops used for biofuel production, it can also significantly lower the cost of biofuel production.

While our model is quite simple and limited because of severely limited data availability, it is nevertheless the first attempt to test and quantify the potential for the role, which genetically modified crops may play in future development of advanced cellulosic biofuels in the Central and Eastern Europe. Further analysis should focus on the extension of the data set to reduce the uncertainty of the results. We suggest inclusion of the field trials and data on fertilizers use into the data set. The work should be also extended on additional crops that can be used for cellulose based biofuels production as soon as the needed data on these crops in Central and Eastern Europe will be available. It would be very valuable to investigate potential of genetical modifications for other plants used for cellulose based biofuels (Miscantus, switchgrass, rye, temperate climate bamboo, etc.).

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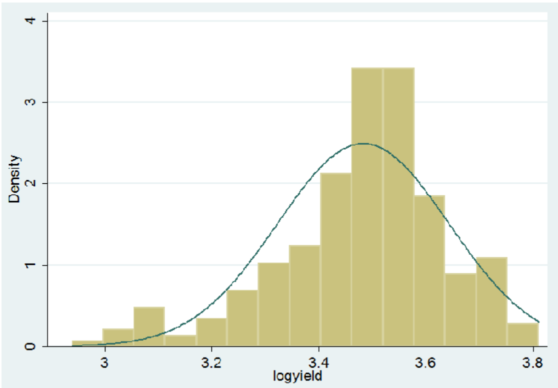
Appendix A

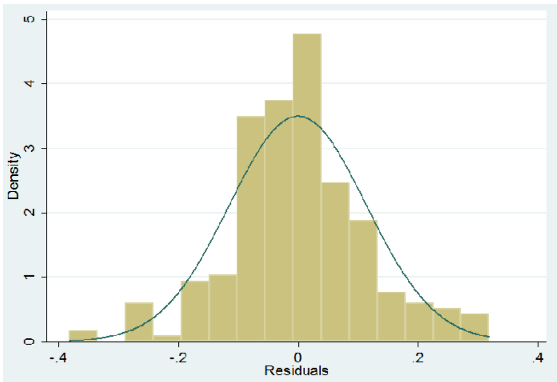
Histograms

Figure A.1: Histogram of *logyield*



Source: Author's computations

Figure A.2: Histogram of residuals



Source: Author's computations

Appendix B

Tables of results

Table B.1: OLS estimation results

Variable	Coefficient	(Std. Err.)
GMshare100	0.004	(0.003)
rmay	0.000	(0.000)
rjune	0.001**	(0.000)
rjuly	0.001**	(0.000)
raug	0.000	(0.000)
tmay	0.029**	(0.008)
tjune	-0.002	(0.007)
tjuly	-0.008	(0.005)
taug	-0.022**	(0.008)
year	0.015**	(0.002)
Intercept	-26.336**	(3.372)
N	252	
R^2	0.492	
$F_{(10,241)}$	23.35	

Significance levels : † : 10% $*$: 5% $**$: 1%

Source: Author's computations.

Table B.2: FE estimation results

Variable	Coefficient	(Std. Err.)
GMshare100	0.006*	(0.003)
rmay	0.000†	(0.000)
rjune	0.001*	(0.000)
rjuly	0.001**	(0.000)
raug	0.000†	(0.000)
tmay	0.023**	(0.007)
tjune	-0.011†	(0.007)
tjuly	-0.021**	(0.005)
taug	-0.031**	(0.007)
year	0.015**	(0.002)
Intercept	-26.809**	(2.999)
N	252	
R^2	0.570	
$F_{(23,228)}$	30.242	

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Source: Author's computations.

Table B.3: RE estimation results

Variable	Coefficient	(Std. Err.)
GMshare100	0.006*	(0.003)
rmay	0.000	(0.000)
rjune	0.001**	(0.000)
rjuly	0.001**	(0.000)
raug	0.000	(0.000)
tmay	0.025**	(0.007)
tjune	-0.008	(0.007)
tjuly	-0.017**	(0.005)
taug	-0.028**	(0.007)
year	0.015**	(0.002)
Intercept	-26.471**	(3.042)
N	252	
Log-likelihood	.	
$\chi^2_{(10)}$	287.353	

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Source: Author's computations.