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Economic Evaluation of GM Plant Breeding Innovations // Ökonomische Bewertungen von GM Pflanzenzüchtungsinnovationen

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Summary

Genetic Modification (GM) or biotechnology in plant breeding is one of the fasted growing innovations in agriculture. Different studies show how GM crops contribute to the need of agricultural productivity increase. However, GM plants are also one of the most controversially discussed agricultural innovations. This dissertation combines different empirical analyses of economic consequences from releases of GM crops. The dissertation is structured as follows:

First, the introduction points out the necessity of agricultural innovations in crop production and explains the current situation of GM crop cultivation regulation in the EU. Further, different generations of GM crops and their welfare effects on different stakeholders along the agricultural value chain are explained. After that, the methodologies applied in the following empirical studies are introduced.

This dissertation contains five empirical studies (*Empirical Studies 1* to *5*). The first two studies (*Empirical Studies 1* and 2) analyze situations of unintended appearances of unauthorized GM seeds. The *Empirical Studies 3* and *4* measure socio-economic potential associated with the release of specific GM crops. In the *Empirical Study 5,* marginal farm-level benefits from a yield increasing innovation in wheat seeds are evaluated.

The case study in the *Empirical Study 1* describes regulatory difficulties and consequences after maize seeds, contaminated with traces of unauthorized GMOs, where planted in Germany in 2010. The study concludes that in such a situation communication between farmers, seed companies, and public authorities need to be improved and legal responsibilities need to be clarified.

In the *Empirical Study 2*, an econometric cointegration approach is used to analyze international futures price reactions after the appearance of unauthorized GM wheat in the U.S. and an ensuing import ban by Japan and the Republic of Korea during June and July 2013. Our findings indicate that during the time of the import ban common cointegration relationships between different wheat futures disappeared. The global market turbulences that were found, indicate limited economic potential of GM wheat.

The *Empirical Studies 3, 4*, and *5* analyze the economic impact of crop innovations at farm level based on European production patterns and conditions.

The *Empirical Studies 3* and *4* both use a similar methodological research framework. Appling a real options approach, Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) associated

with GM breeding innovations are determined for Germany. The GM breeding innovations herbicide resistant (HR) rapeseeds (*Empirical Study 3*) and yield increasing wheat (*Empirical Study 4*) are considered. MISTICs identify an upper bound for social incremental irreversible costs (SIICs) from the introduction of an innovation, up to which the release of the new technology can be considered socio-economically justified. Both studies report positive MISTICs values and thus conclude on potential benefits to famers and the environment. Nevertheless, with the current ban of these technologies, German society passes up the potential benefits for the sake of a GMO free agricultural crop production. One can conclude that the German society weighs perceived SIICs higher than perceived potential benefits of the technologies.

In the *Empirical Study 5* stochastic frontier analysis is applied and multi-output multi-input distance functions constructed to observe economic relationships between inputs and outputs for European crop production. More specifically, the importance of seeds as an input in wheat production for European crop farmers is analyzed. Eventually, marginal shadow values for yield increasing wheat seeds are derived.

The *Empirical Studies 3, 4,* and *5* conclude that plant breeding innovations offer potential benefits for European crop farms. However, GM based plant breeding innovations raise also society concerns which implies regulatory challenges for political decision makers. Further, regulatory complications if unauthorized GMOs appear within the supply chain are indicated in the *Empirical Studies 1* and *2*.

Zusammenfassung

Genetische Modifizierung (GM) bzw. Biotechnology in der Pflanzenzucht ist eine der schnellst wachsenden Innovationen innerhalb der Landwirtschaft. Verschiedene Studien zeigen wie GM Nutzpflanzen zur benötigten landwirtschaftlichen Produktivitätssteigerung beitragen. Zugleich ist GM Pflanzenzucht eine der am kontroversesten diskutierten landwirtschaftlichen Innovationen. Diese Dissertation verbindet verschiedene empirische Studien zu sozioökonomischen Konsequenzen durch Freisetzungen von GM Nutzpflanzen. Die Struktur dieser Dissertation ist wie folgt:

Zuerst stellt die Einleitung die Notwendigkeit landwirtschaftlicher Innovationen heraus und erklärt den derzeitigen Stand des globalen Anbaus von GM Nutzpflanzen und deren Regulierung in der EU. Weiter werden verschiedene Generationen von GM Nutzpflanzen und deren Wohlfahrtseffekt für verschiedene Stakeholder entlang der landwirtschaftlichen Wertschöpfungskette dargestellt. Daran anschließend werden die Methoden, welche in den folgenden Kapiteln angewandt werden, vorgestellt.

Die Dissertation beinhaltet fünf empirische Studien (*Empirical Studies 1* bis *5*). Die ersten beiden Studien (*Empirical Studies 1* und 2) analysieren Situationen, in denen nicht autorisiertes GM Saatgut unbeabsichtigt auftrat. Die Studien in den *Empirical Studies 3* und 4 zeigen das sozioökonomische Potenzial assoziiert mit der Einführung spezieller GM Nutzpflanzen. In der *Empirical Study 5* werden betriebliche Grenznutzen durch ertragssteigernde Innovationen im Weizensaatgut bewertet.

Die Fallstudie in der *Empirical Study 1* beschreibt regulatorische Schwierigkeiten und Konsequenzen nachdem Maissaatgut, welches mit Spuren von nicht autorisierten genetisch modifizierten Organismen (GMOs) kontaminiert war, in Deutschland 2013 ausgesät wurde. Die Studie schlussfolgert, dass in einer solchen Situation Kommunikation zwischen Landwirten, Saatgutunternehmen und zuständigen Behörden verbessert werden muss und rechtliche Zuständigkeiten geklärt werden müssen.

In der *Empirical Study 2* wurde eine Kointegrationsanalyse verwendet um die Reaktion internationaler Futures Preise zu analysieren, nachdem nicht autorisierten GM Weizen im U.S. Bundesstaat Oregon auftrat und zu einem Importverbort von Japan und Südkorea während Juni und Juli 2013 führte. Unsere Ergebnisse deuten darauf hin, dass die gewöhnlichen Cointgrationsbeziehungen zwischen den verschiedenen Weizen Futures während des Importverbotes verschwanden. Diese gefundenen globalen Marktturbolenzen deuten das limitierte ökonomische Potential von GM Weizen an.

Die *Empirical Studies 3, 4* und *5* analysieren die Auswirkungen von Nutzpflanzeninnovationen auf landwirtschaftlicher Betriebsebene basierend auf europäische Produktionsabläufe und -bedingungen.

Die *Empirical Studies 3* und *4* verwenden beide einen ähnlichen methodischen Rahmen. Mittels eines Real Optionen Ansatzes werden maximale zusätzliche sozial tolerierbare irreversible Kosten (MISTICS[1]), welche mit GM Züchtungsinnovationen in Verbindung stehen, für Deutschland bestimmt. Als GM Züchtungsinnovationen sind Herbizidresistenter Raps (*Empirical Study 3*) und Hochertrags-Weizen (*Empirical Study 4*) beachtet. MISTICs sind Grenzwerte unter denen zusätzliche soziale irreversible Kosten von Innovationen liegen müssen, damit ihre Einführung sozio-ökonomisch sinnvoll ist. In beide Studien wurden positive MISTICs und damit potentielle Nutzen für Landwirte und Umwelt bestimmt. Dennoch verzichtet die deutsche Gesellschaft, mit dem derzeitigen Verbot dieser Technologien, auf potentiellen Nutzen zum Zwecke einer GMO-freien landwirtschaftlichen Nutzpflanzenproduktion. Daraus ergibt sich die Schlussfolgerung, dass die deutsche Gesellschaft wahrgenommene zusätzliche soziale irreversible Kosten höher gewichtet als den wahrgenommen potentiellen Nutzen dieser Technologien.

In der *Empirical Study 5* wird stochastic frontier analysis angewandt und multi-output multi-input Distanzfunktionen konstruiert um ökonomische Beziehungen zwischen Input und Output innerhalb der europäischen Nutzpflanzenproduktion zu beobachten. Konkret wird die Bedeutung von Saatgut als Produktionsinput für die Weizenproduktion europäischer Ackerbauern analysiert. Letztendlich sind marginale Schattenwerte für ertragssteigerndes Weizensaatgut bestimmt.

Die *Empirical Studies 3, 4* und *5* schlussfolgern, dass Pflanzenzüchtungsinnovationen potentielle ökonomische Vorteile für europäische Ackerbauern bieten. Jedoch führen GM basierte Innovationen zu gesellschaftlichen Bedenken womit die derzeitige Situation regulative Herausforderungen für politische Entscheidungsträger impliziert. Des Weiteren, werden in den *Empirical Studies 1* und *2* regulative Schwierigkeiten aufgezeigt, wenn nicht autorisierten GMOs in der Wertschöpfungskette auftreten.

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[1] Maximum Incremental Social Tolerable Irreversible Costs (MISTICs)

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C	carbon
DF	distance function
DG SANTE	Directorate General for Health and Food Safety
DNA	Deoxyribonucleic acid
EC	European Commission
ECM	European Council of Ministers
EU	European Union
EFSA	European Food Safety Authority
FDA	Food and Drug Administration
GHG	Greenhouse gas
GM HR	Genetically modified herbicide resistant
GURT	Genetic Use Restriction Technology
ha	Hectare
HR	Herbicide resistance
IR	Insect resistance
M&A	Merges and acquisitions
NDV	Newcastle Disease Virus
NGOs	Non-governmental organizations
PBR	Plant breeds rights
PPP	Public-private partnerships
R&D	Research and development
RO	Real rptions
ROI	return on investment
ROW	Rest of the world
SFA	Stochastic frontier analysis
SIICs	social incremental irreversible costs
SMOs	social movement organizations
SOC	sequestering soil organic carbon
TGW	thousand grain weight

U.S.	United States of America
USD	United States Dollars
USDA	United States Department of Agriculture
WTP	Willingness to pay

1 Introduction

Agricultural plant breeding innovations have been and will be a determining factor for the development of humanity and nature. Their impact on agricultural productivity and food quality are essential in the challenge of feeding more than 8 billion people on the planet.

The technology of genetic modification (GM) develops in plant breeding since the early 1990. GM technology offers a broad range of opportunities to improve, accelerate and supplement conventional plant breeding methods. However, unlike earlier plant breeding methods, GM technology is seen critical by large parts of many societies worldwide. While proponents emphasize the potential benefits, opponents warn of the hazards associated with the new technology. The situation leads to complex regulatory challenges. Some countries adopt GM technology in their agricultural production, others, such countries in the European Union (EU), have largely banned its cultivation on their territories.

Necessity and challenges for agricultural innovations

Innovations in agricultural production are crucial in order to meet current and future demands for food safety and food security[2] (FLOROS et al., 2010). The FAO estimates that 12.5% of the world's population (868 million people) are undernourished in terms of energy intake (FAO, 2013). For the future the situation is likely to become more severe. Current projections indicate that the world population will increase from 7.3 in 2015 to 8.5 billion by 2030 and 9.7 billion in 2050 (UNITED NATIONS, 2015). At the same time food consumption will change and the average demand for calories per person will grow due to economic development. The combination of both effects leads to the projected annual growth rate of total world consumption of all agricultural products of 1.1% from 2005/2007 to 2050 (ALEXANDRATOS and BRUINSMA, 2012).

In the past, agricultural production could keep up with increasing demand by the adaptation of various innovations. With the first green revolution, starting in the 1960, productivity increased due to introduction of industrial fertilizer and agro-chemicals (herbicides and pesticides) and innovations in farming practices, agricultural technology, and plant breeding. Further, during 1961 and 1999, absolute production growth in agricultural output was achieved through a 12% increase in the global area of cropland and a 10% rise in the area of permanent pasture (GREEN et al., 2005).

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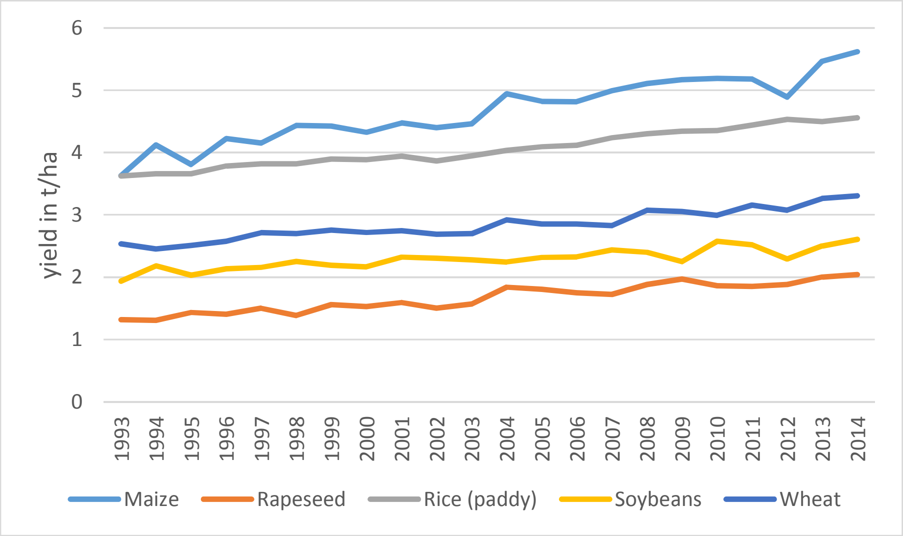
[2] Food safety refers to quality characteristics of food product. Food security is related to the supply and accessibility of food products.

Between 1993 and 2013 total production increased for maize (84%), rapeseed (147%), rice (38%), soybeans (110%), and wheat (18%). That increase was driven by a relative yield increase in combination with the expansion of production areas for maize (36%), rapeseed (73%), rice (10%), soybeans (77%), and wheat (3%) (FAO, 2015). The latest yield increase per ha for maize, rapeseed, rice, soybeans, and wheat are shown in *Figure* 1.

Figure 1: Global yield development for selected crops



Source: Author's own compilation based on FAO (2017b)

For the future, further increase in total yield due to the expansion of agricultural production is limited and dangerous to the environment. Cropping intensification with an increasing application of fertilizer and agro-chemicals might increase yields in developing countries but also has limited potential. At the same time farming inputs need to be embedded in more sustainable production systems to save resources, minimize environmental impacts, maintain biodiversity, and guarantee soil fertility. Further, climate change will challenge agricultural production systems in terms of their adaptability and stability (BONNY, 2014). In this context, plant breeding innovations will play an important role. But in order to increase food availability not just primarily food production must be considered. Different levels along the agricultural supply chains, starting with post-harvest losses and ending with food waste management, need to be improved. Improved crop yields are expected to be most important for increasing food availability (ALEXANDRATOS and BRUINSMA, 2012). Different GM plant breeding innovations offer the potential to improve crop yields and food quality but pose uncertain hazard to society. Therefore, it is important to critically analyze and discuss this technology.

2 Research aims

Political decisions about the approval of GM crops need to consider the potential positive as well as their potential negative contribution to society's welfare. Currently, by a strong interpretation of the precautionary principle, the EU mostly excludes itself from potential benefits from cultivation of GM crops.

The overall research aim of this dissertation is to provide empirical analyses of economic consequences and potential of GM crop technology applications. Empirical studies on past events and potential future scenarios, using different methodologies, are conducted to approach this topic from different perspectives. The focus of these studies is on the consequences of the appearance or production of GM crops. The study objective in this dissertation is German (*Empirical Studies 1, 3,* and *4*) and European (*Empirical Study 5*) agriculture crop production with the exception of *Empirical Study 2* where global market reactions are compared.

The dissertation's aim is not to give advice on whether to deregulate the use of GM crops for German or European agriculture. Rather, each study has the aim to contribute to the social political discussion about GM crops by giving an objective assessment of its economic consequences. Taking different perspectives, approaching different research questions and applying different methodologies should also point out versatility within the economic assessment of GM plant breeding innovations. Further, the designed methodological frameworks for the specific research question contribute to the existing theories on economic assessment of agricultural innovations.

2.1 Structure of the dissertation

The remainder of this dissertation includes background information on the role of GM crops and an overview on the applied methodology. Five empirical studies build the core of this dissertation. The first two studies (*Empirical Studies 1* and *2*) analyze situations of an unintended appearance of unauthorized GM seeds. In the *Empirical Study 1,* a case study shows the regulative challenges linked to the unintended appearance of GM Maize in Germany. In the *Empirical Study 2*, we analyze global trade implications linked to GM wheat appearance in the U.S. using econometric cointegration analyses. The analyses in the *Empirical Studies 3* and *4* indicate socio-economic welfare potential associated with the release of GM herbicide resistant (HR) rapeseeds and GM yield-increasing wheat crops, respectively, for Germany. In both empirical studies, real options (RO) theory is applied. In the *Empirical Study 5*, marginal farm-level benefits of a yield-increasing innovation in wheat production are studied using stochastic frontier analysis. The dissertation continuous with a general discussion of the findings and policy relevant conclusions. Finally, publications and authors’ contribution as well as acknowledgements are presented.

3 Background on GM crops

This section provides an overview on the development of genetically modified organisms (GMOs) and the role of GM crops in agriculture and society.

First knowledge on the variability and feasibility of GMO applications developed in the early 1970s. In 1982 the first commercial product based on GM technology–human insulin from the company Eli Lilly & Co.'s Humulin–reached the market. Such pharmaceutical products are associated with *red biotechnology*. Since 1984 GMOs are employed within food production. The first applications of such so called *white biotechnology* were enzymes from GM bacteria for bakery processes and GM yeast cells, which contain the bovine chymosin gene, for cheese production (WESSELER, 2014).

GM innovations in the context of plant breeding are referred to as *green biotechnology*. China was the first country to introduce GM plants with a virus resistant tobacco in 1992 (JAMES and KRATTIGER, 1996). The introduction of FLAVR SAVR tomato in America by Calgene in 1994 was the first market commercialization of a GM food product. The FLAVR SAVR was characterized by its ripping process that could be decoupled from an associated softening of the fruit shelf, which is beneficial for transportation and industrial usage. In 1996 pasta sauce from FLAVR SAVR tomatoes, which were grown and processed in California, was introduced to the UK. The product, labeled as “derived from GM tomatoes”, was sold at the UK grocery chains Sainsbury’s and Safeway for three years. In 1999 Sainsbury’s and Safeway removed the product from their shelves after consumers became sensitized to possible health risks of GM products (BRUENING and LYONS, 2000). Different to today’s dominating GM crops, the FLAVR SAVR tomato was developed with respect to its product and not to its cultivation characteristics. Today’s most important GM crop characteristic are the so-called first generation (generation I) or production traits; insect resistance (IR) and herbicide resistance (HR), both developed for their agronomical advantages (see *Section 3.3.1*).

In 1995 nine transgenic crops where approved for commercial cultivation mainly in the U.S. and Canada but also in China, Australia, Latin America and the European Union. Those crops (by companies) included BT cotton, BT maize, BT potato (all Monsanto), HR soybean (Monsanto), HR cotton (Calgene) and high lauric acid canola (Calgene) (JAMES and KRATTIGER, 1996). The commercial application of GM crops spread rapidly around the world, in both industrialized and developing countries. The total global production area of GM crops increased from 1.7 million ha in 1996 to 181.5 million ha in 2014. That implies an annual average increase of ca. 11% of global GM cultivation area since 2000 (JAMES, 2014). Today, 11 different plant species carrying GM traits are commercially cultivated in 28 countries (primarily in North- and South America) by around 18 million farmers. Out of the 28 countries, 20 are developed and 8 are developing (JAMES, 2014). The actual cultivation area of GM crops might be even larger due to *stealth seeds*. For instance, it is well known that farmers in countries like Mexico, Vietnam, Thailand, Pakistan and Ukraine use GM seeds without official deregulation (HERRING, 2010). Besides the 28 countries with official cultivation of GM crops, an additional 31 countries had granted regulatory approval for imports or use of different GM crops in 2012 (BENNETT et al., 2013).

The percentage of land cultivated with GM crops varies between countries. The USA has the highest share of GM crop production (40%), followed by Brazil (23%), Argentina (14%), India (6%), and Canada (6%) (STATISTA, 2015). Worldwide, the four most cultivated GM crops are soybean, maize, cotton, and rapeseeds (see *Table 1*).

Table 1: Global distribution of GM/transgenic traits over crop species in 2014

Crop species	**Area (in million ha)**	**Share of area with GM/transgenic traits**
Soybean	90.7	50%
Maize	55.2	30%
Cotton	25.1	14%
Rapeseeds (Canola)	9.0	5%
Others	1.5	1%
Total	181.5	100%

Source: Author's own compilation based on James (2014: 198)

Soybeans are also the crop with the highest relative share of GM varieties. Around 79% of the global annual production have either HR and/or IR events[3] (JAMES, 2014).

3.1 Agricultural crop breeding

Agricultural innovations started with the invention of agriculture itself. Around 10,000 years ago, human kind shifted from nomadic hunting and gathering to more managed forms of food, feed, and fiber production. From then on human kind gathered experience with domestication and breeding of plants (PARDEY et al., 2010). The domestication of crops by saving seeds from one harvest to plant in

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[3] An event is a unique DNA recombination, which is used to generate transgenic plans.

the next growing season has been the first step towards a coordinated crop production. In a next step, farmers acquired knowledge about different varieties and by repeated selection they adopted the varieties to the prevailing environmental conditions. After those first forms of selection breeding more advanced breeding methods, such as hybridization[4], mutagenesis, inbred, and GM technology, developed during the last 100 years. The development of breeding innovations is usually linked to changes in farming practices. For example, modern plant breeding integrated the increased usage of fertilizer management with new dwarf varieties of wheat and rice (Bennett et al., 2013).

3.1.1 GM plant breeding

GM or genetic engineering (GE) or *green biotechnology* stands for a broad range of recent breeding innovations. In general, the terms describe the application of molecular biology in plant breeding. However, for some technologies it is not clear if they count as a GM technology. For instance, there is an ongoing discussion if technologies such as marker-assisted selection, in vitro propagation of plants, embryo rescue via micro propagation, and specialized mutation breeding strategies such as targeting induced local lesions in genomes (TILLING) should be considered as a GM technology (Bennett et al., 2013).

GM crops are characterized by one or more events for desirable traits inserted through GM or GE. An event is a unique gene sequence, which may be generate out of the DNA of other plant species or living organism. The recipient crop then shows the desired manifestations of the inserted event. It is also possible to remove or disable a specific gene of the target crop to suppress its manifestation (Key et al., 2008). Through the ability to transfer novel genes into plants by non-sexual means, GM technology expands the gene pool available for crop improvement from a narrow base of closely related plant species to a theoretically infinite gene pool. Thereby, the technology might overcome limits of conventional breeding methods. Further, GM technology allows for faster development of new crop traits (Bennett et al., 2013). GM and conventional breeding techniques can aim similar breeding aims. Potential breeding aims include improvement of plant characteristics in terms of drought and salt tolerance, yield potential, and nutrient contents as well as changing plant characteristics to facilitate input saving and special cropping patterns.

For the subsequent empirical analyses, we focus especially on high-yielding wheat (*Empirical Studies 4* and *5*) and HR rapeseeds (*Empirical Study 3*) derived through GM breeding. In the following we introduce the respective crops and characteristics in more detail.

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[4] Hybridization is a plant breeding process in which inbred lines are crossed to create more vigorous plants with greater yield potential than exhibited by either parent. However, this so-called ‘heterosis effect’ of hybrids is not transmitted to its offspring.

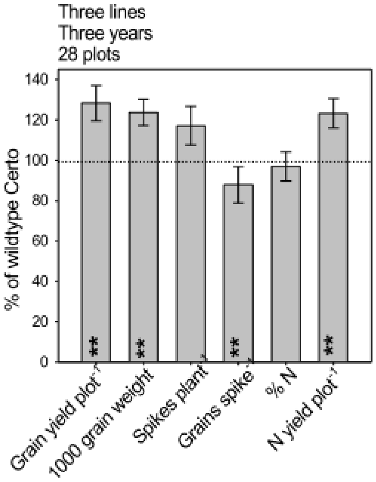
GM high-yielding wheat (HOSUT)

Globally speaking, wheat *(triticum aestivum)* is the most important source for carbohydrate in human nutrition and meets about 20% of the world's calorie and protein demand (SHIFERAW et al., 2013). Wheat accounts for approximately 30% of global grain production and for 45% of the cereals used as food (CHARMET, 2011). Major production sites are South and East Asia, Western Europe, Eastern Europe, Russia, and North America. The world's greatest wheat producers are China, India, and the U.S.. Germany is the world's ninth greatest wheat producer (FAO, 2015).

A global wheat production that is both sustainable and increasing is essential to cope with the challenges of food security and a growing human population. However, between 1997 and 2007 the actual rate of wheat production increased by only 0.5% per year and failed to meet the required 1.4% (REYNOLDS et al., 2009). Production increase through expansion of agricultural land is limited and in some regions farmable land even decreases due to climate change. At the same time, increase in relative yield per ha decelerates and approaches an upper limit (FISCHER and EDMEADES, 2010, PELTONEN-SAINIO et al., 2009, RAY et al., 2012). The reasons are, first, climate change and its implemented increased temperature and production risk (LOBELL et al., 2011), and second, the lack in genetic progress (BRISSON et al., 2010). Already in recent years, wheat yields have been improved by harvest index increases and much less by higher biomass gain (Reynolds et al., 2009). GM technology offers a possibility to stimulate the genetic improvement of wheat varieties for yield stability and increase. But in contrast to other major crops, no GM wheat got ever marketed even though technologies would be available. Already in the 1990's Monsanto developed GM herbicide resistant (HR) wheat. BERWALD et al. (2006), WILSON et al. (2008), and JOHNSON et al. (2005) analyzed farm level and socio-economic effects from a possible introduction of GM HR wheat in the U.S. and Canada. The studies conclude that the existence of market externalities and segregation costs, mainly because of a relatively big export market, which is reluctant towards GM wheat, and a smaller domestic market, remove the advantage for wheat producers from an approval of GM wheat varieties. Eventually, the U.S. and Canada commonly decided not to introduce GM (HR) wheat and to not risk foreign export markets. Due to that decision also other available GM traits for wheat, such as drought resistance and high-yielding, are unlikely to reach commercial status anytime soon.

In spite of the ban of GM HR wheat, such plants were found in fields in Oregon, U.S. in 2013. In the *Empirical Study 2*, we analyze price reactions and interactions in the global wheat market as a result of this event. In the *Empirical Studies 4* and *5*, we focus on the potential economic effects of high-yielding GM wheat. A high-yielding trait named HOSUT has been developed by the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), a German nonprofit research institution. Researchers were able to introduce the barley sucrose transporter HvSUT1 controlled by the barley Hordein B1 promoter into the conventional winter wheat variety named Certo. The result of the breeding experiment are different HOSUT lines. Three of the HOSUT lines were grown over three years in micro-plots. Grain yield per plot significantly increased by an average of 28.2% when compared to the non-transformed control wheat Certo as shown in *Figure 2*. Simultaneously, relative protein concentration slightly decreased and concentrations of iron and zinc both increased by approximately 30%. The enhanced yield performance is expressed by an increase of 23% in the thousand grain weight (TGW) (Saalbach et al., 2014).

Figure 2: Average changes of yield related parameters of three HOSUT lines over three growing seasons



*Note: A total of 28 plots (0.5 m² with 200 plants) were evaluated. Significant differences to wildtype Certo are given by asterisks. *, P > 0.05; **; P > 0.001*

Source: Saalbach et al. (2014)

There might be reasonable doubt that the yield increase shown in the micro plots cannot be reached under practical farming conditions. However, open field trails could give more information on the innovation's potential.

Since HOSUT lines were developed by a nonprofit research institution (IPK) the technology is not protected by intellectual property rights (IPR). On the one hand, this might have a positive impact on public acceptance of the technology. On the other hand, it makes the technology less attractive for private companies and their investment in its further development.

GM HR rapeseeds

The annual global rapeseed *(Brassica napus L.)* production is about 72.5 million tons (FAO, 2015). The main production sites are Europe, North America, China, India, and Australia. Europe is the world's most important rapeseed region with a production of 25.6 million tons in 2013. Within Europe, Germany and France account for about 40% of the annual production. The largest rapeseed producer is Cnanda (FAO, 2015).

Rapeseed production experienced a strong increase after the development of varieties without erucic acid and low glucosinolate content—so called 00 varieties—in the 1980s (BECKER, 2011). This breeding innovation facilitated rapeseed's usage as food and feed. Later, hybrid varieties were developed and introduced to the German market in 1995. One of the latest breeding innovation in rapeseeds are GM HR varieties to simplify weed management systems. HR plants facilitate no-tillage productions systems, which are seen as a more sustainable and extensive faming practice (TRIPLETT and DICK, 2008). Such a system is based on the resistance of the target crop (rapeseeds) to a total herbicide (e.g. glyphosate). Due to the resistance, the target crop can be directly planted into the soil without a previous tillage step. In the following, weed control treatments only the non-target or non-residence plants (weeds) are affected by the total herbicide. The gene sequence, which confers tolerance to the total herbicide glyphosate was discovered in a naturally occurring soil bacterium and with GM breeding techniques successfully transferred to the gene of many crops beside rapeseeds, e.g. soybean, sugar beet, wheat, and maize. Plants with HR gene sequence produce an enzyme, which blocks the effect of glyphosate.

Varieties with HR characteristics are developed not only using GM technologies (GM HR rapeseeds) but also conventional breeding (Clearfield rapeseeds). GM HR varieties are only cultivated in Canada, the U.S., Australia, and Chile. In 2012 about 24% of the global annual rapeseed production on 34 million ha was GM, with an upward trend (JAMES, 2013). In Canada, the adoption rate of GM HR rapeseed was 98%, equals 8.37 million ha, in 2012. In Europe, HR Clearfield rapeseeds were introduced 2011. Clearfield rapeseeds are resistant to ALS-inhibitors, which are less broad herbicides compared to, for example, glyphosate.

3.2 European regulation on GMOs in agriculture

In terms of consumption the EU highly depends on GM crop production. In 2013 the EU imported around 27.9 million tons of soybean and soybean meal to cover about 60% of the demand for protein. This amount is equal to 60 kg per EU citizen. About 90% of the imported soybeans, which are mainly produced in North and South America, are GM (TILLIE and CEREZO, 2015).

The first GM crop actually cultivated in the EU (France and Spain) was the IR maize variety MON810 from Monsanto in 1998. Other European countries such as Germany, Portugal, Czech Republic, Slovakia, Romania, and Poland followed. Currently, only two GM events–MON810 in maize and Moonshadow 2 for carnation are approved for cultivation in the EU (GMO-COMPASS.ORG, 2015). Moonshadow 2 carnations are only cultivated in the Netherlands and IR MON810 maize only in Spain, Portugal, the Czech Republic, Slovakia, and Romania (GMO-COMPASS.ORG, 2015). Compared to the entire maize cultivation area in Europe, GM maize accounts for only about 1.5% (DESTATIS, 2015). In the past, European cultivation authorizations also existed for the GM potato Amflora, two GM rapeseeds (MS1 x RF1 and MS1 x RF2) and another GM maize (BT176). However, those authorizations have not been renewed. Nonetheless, 63 additional events for cotton, maize, rapeseed, rice, soybean, sugar beet, and carnation have valid authorization for food and feed and/or import and processing (GMO-COMPASS.ORG, 2015)

After the market introduction of MON8010 maize in 1998, the member states Denmark, France, Greece, Italy, and Luxembourg declared in June 1999 that they will take steps to suspend any new authorizations for growing and placing GMOs until the European Commission "*put in place a tighter, more transparent framework, in particular for risk assessment, having regard to the specifics of European ecosystems, monitoring and labelling*"(EU ENVIRONMENTAL COUNCIL, 1999). Similarly, the member states Austria, Belgium, Finland, Germany, the Netherlands, Spain, and Sweden declared, due to increasing public concern, the need for a *"more transparent and strict framework concerning critical issues such as risk assessment taking into account the specificity of European ecosystems, monitoring and labelling as well as the need to restore the trust of public opinion and of the market"* (EU ENVIRONMENTAL COUNCIL, 1999). Further, they referred to a *"precautionary approach in dealing with notifications and authorizations for the placing on the market of GMOs"* and assigned *"not to authorize the placing on the market of any GMOs until it is demonstrated that there is no adverse effect on the environment and human health"* (EU ENVIRONMENTAL COUNCIL, 1999). As a result, the EU realigned the GMO approval framework. The EU Directive 2001/18/EC was published to make the procedure for cultivation and market placing of GMOs more efficient and more transparent. The legislation act declares that the Commission is obliged to consult scientific committees for health and environmental risks and may even for ethical concerns (EUROPEAN UNION, 2010).

In 2003 the regulation 1830/2003/EC specified the directive 2001/18/EC concerning traceability and labelling of food and feed products from GMOs. It introduces a threshold level of 0.9 % for approved GMOs until a product does not require labeling. A 'GM-free' claim can only be used on a product containing less than 0.1 per cent authorized GM content. For non-authorized GMOs there is a zero-tolerance level (EUROPEAN COMMISSION, 2013). Practical experience and problems of a zero tolerance level for seeds are discussed in the *Empirical Study 1*.

3.2.1 Approval process

Concerns about the environmental and human health risks of GM crops together with pressure from lobby groups led to a complex European regulatory framework. Thereby, the EU follows a strong interpretation of their precautionary principle. In the EU, GM products are, due to their breeding origin, seen as not substantially equivalent to conventional products. Thus, they are treated in a separate deregulation process. This is different to, for example, the U.S.. As soon a GMO passes the test by the USDA or Food and Drug Administration (FDA), it is treated as a conventional organism (HAAS et al., 2009).

The EU directive 2001/18/EC regulates the deliberate release of GM crops into the environment and establishes procedures to assess the environmental risk and general traceability and labeling principles. Based on the legal framework, a GM crop can be approved for cultivation and/or for usage as food and feed. The approval process starts with an application to an EU member state for the concerning GM crop filed by the applicant, usually a seed company. After confirming that all required documents are present the European Food Safety Authority (EFSA) conducts a risk assessment based on studies, conducted and compiled by the applicant, within six months. EFSA submits its opinion to the European Commission (EC) and to the member states and publishes it for the public. After that the Directorate General for Health and Food Safety (DG SANTE)[5] of the EC drafts an approval decision, based on the EFSA's risk assessment report, to the Standing Committee on the Food Chain and Animal Health. If the EC's draft for a decision is different from EFSA's opinion, written justification is required. The Standing Committee decides on the EC's draft with qualified majority. At this stage the GM crop can be approved or not. If the Standing Committee fails to decide, the EC must take its position to the European Council of Ministers (ECM) and inform the European Parliament. Now the ECM decides with a qualified majority vote and the GM crop is approved if the decision is in favor of the EC's draft. The authorization has a maximum duration of ten years and can be renewed. If the ECM rejects or fails to approve the EC's draft with qualified majority, the EC must revise the draft. After approval of a GM crop, Member States can adopt the emergency measure 'OPT-OUT' based on new identified risk on health and environmental grounds or for environmental and agricultural political reasons, such as territorial planning and coexistence difficulties (EUROPEAN COMMISSION, 2016b). Based on this, each member state can decide on cultivation and usage as food and feed of approved GM crops on their territory. Due to high regulative effort, costs in combination

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[5] The regulative authority for food and feed (including GMOs) was moved from DG Agriculture to the DG SANTE in 1999.

with the general low market potential of GM crops, most seed companies retrieve their research and business activities with GM products from Europe.

3.3 GM crops generations

The term GM crop, which describes a certain breeding technique, stands for a broad range of different crop characteristics, e.g. IR, HR, yield increase, nutrition improvement or salt and drought tolerance. According to its characteristics, GM crops are distinguished into three different generations. Generation I and II GM crops are rather designed for common feed and food production compared to generation III GM crops, which are rather associated with pharmaceutical and industrial usages. Generally speaking, generation I GM products mainly benefits the crop producer (reduce production cost) and generation II and III GM products benefit mainly the consumer (higher quality).

GM innovations in plant breeding are developed by public or private research. The public sector is more present in early stage research, but its role diminishes as the R&D pipeline reaches advanced stages. Innovations that are brought to the market are usually developed by private seed companies, at least in the final development stage (BENNETT et al., 2013). Currently, GM innovations introduced to the market are associated with incremental economic farm performance, thus, with generation I GM crops. Generation II and III GM crops have lower economic market potential and thus, lower incentives to be developed by the private sector. Therefore, those crops are rather developed by public research or by public-private partnerships (PPP). Today, no crop variety with generation II and III characteristic is commercially available.

3.3.1 Generation I

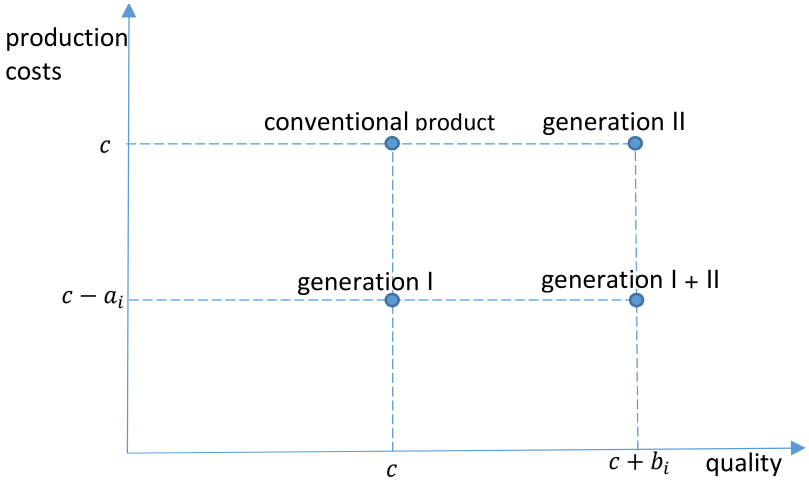
Agronomic characteristics of generation I GM crops are improved in order to simplify cultivation and reduce farm inputs or production costs. Nearly all commercial cultivated GM crops, today, are associated with the generation I GM traits insect resistance (IR) and HR (EVANS and BALLEN, 2013). IR crops—also known as *Bt* varieties—produce the enzyme *Bacillus thuringiensis (Bt)*, which is toxic to many major crop pests (insects) but not to mammals. HR crops are varieties, which are not affected by total herbicide substances such as glyphosate, commonly known as Roundup, or glufosinat. Varieties with more than one GM event are called stacked variety. Other generation I GM technologies that are being developed include fungal, bacterial, and virus resistance in major cereal as well as in root and tuber crops (Halford 2006). Further, generation I can be extended to characteristics, which would improve the crop's yield productivity and by that reduce the relative production costs. Those characteristics such as yield increase, tolerance to abiotic stress (e.g. drought and salt), nutrient-use and photosynthetic efficiency, are often based on more complex DNA recombinations. The increased productivity of agricultural production systems due to GM innovations also has the potential to conserve resources and reduce pollution and thus to benefit the entire society.

3.3.2 Generation II

Generation II summarizes crops with output improvements due to GM (LHEUREUX and NETWORK, 2003). It refers to quality oriented characteristics which are beneficial to consumers (i.e. nutritional enhancement). A famous example for generation II GM crops is Golden Rice, a GM based rice variety, which contains significant amounts of provitamin A not just in the leaf but also in the kernel. Further examples are wheat with higher iron (BORG et al., 2012) or starch (REGINA et al., 2006) content. Enhancing food crops with higher nutrient contents through conventional or GM breeding is also called biofortification. Other biofortification projects include the development of GM sorghum, cassava, banana, and rice enhanced with multiple nutrients.

In *Figure 3*, we follow MOSCHINI and LAPAN (2006) and distinguish generation I and II according to their production costs and quality.

Figure 3: Generation I and II GM Products



Note: A given GM innovation (labeled by the subscript i) is indicated by decreasing production cost from c (conventional) to $c - a_i$ or increasing quality from c to $c + b_i$.
Source: Author's own compilation based on Moschini and Lapan (2006)

Generation I crops create a direct value to farmers through decreasing production costs. Therefore, those traits will be economically beneficial to farmers (GOURE, 2004). Generation II traits lack economic incentives to seed developers and farmers. Today, crop products are mostly treated as bulk commodities and their price is determined by more general quality aspects such as protein content. The content of vitamins or minerals, does not affect the market price. Thus, farmers do not have an incentive to pay developers for the innovation. As a consequence, currently, it is unlikely that generation II traits are developed by the private sector.

3.3.3 Generation III

Generation III GM crops are designed to produce special substances, which can be extracted from the plant and manufactured for pharmaceutical or industrial usages. Pharmaceutical examples are the production of insulin or anti genes against the hepatits B virus in tobacco, the production of fusion proteins in maize against the Newcastle Disease Virus (NDV) in chicken (Phillips, 2008), oilseeds with improved fatty acid profiles, high-amylose maize, and high-amylopectin potatoes.

3.4 Welfare effects of GM crops and their distribution

Economic studies on the cost and benefits and the social welfare effects of GM crops are important for decision-making at several stages. Seed developers will consider potential return for their investment into R&D. Policy makers need to consider the impacts on the entire society when deciding about an innovation's deregulation. Eventually, farmers decide about the adoption of a new technology depending on their private costs and benefits.

The different GM generations are associated with different and similar impacts on the groups; seed developer, farmer, society, consumer and environment. *Table 2* generally indicates potential welfare effects on the groups comparing GM to conventional crops.

Table 2: Potential welfare effects from GM traits

Innovation type		**Seed developer**		**Farmer**	**Society (Consumer or Taxpayer)**				**Environment**
Gen. I	BT	Higher seed prices	Various economic effects from market concentration	Production security, flexibility, cost savings, worker safety, yield increase		Lower food prices due to productivity increase (food security) as a secondary effect	Regulation and segregation costs (coexistence cost)	Potential irreversible costs	Reduction in pesticides and fuel usage, preservation of biodiversity
	HR	Higher seed prices		Production security, flexibility, cost savings, yield increase					Changes in agro-chemical usage, Reduction in fuel usage, increase in soil quality (no-tillage systems), Expansion of cultivation area
	High yield	Higher seed prices		Production increase					
	Tolerance to abiotic stress	Higher seed prices		Production security,					
	Nutrient-use efficiency	Higher seed prices		Production security, cost savings					
Gen. II	Nutritional enhancement	Low potential benefits from higher seed prices			Food quality increase				
Gen. III	Adjusted qualities for industrial usage	Potential benefits from higher seed prices			Innovative industrial products				Environmental friendly industrial inputs
	Special substances for pharmaceutical usage	Potential benefits from higher seed prices			Innovative pharmaceutical products				Environmental friendly industrial inputs

Note: Innovation type with (Generation (Gen.) and trait)

The table generally indicates potential welfare effects for different groups comparing GM to conventional crops.

Source: Author's own compilation based on reviews on the effects of GM innovations including Kalaitzandonakes (2012), Qaim (2009), and Zilberman et al. (2010).

Bennett et al. (2013) estimated the cumulative direct economic benefits of GM crops between 1997 and 2007 to be 44.1 billion USD, equally distributed between farmers in developed and developing countries. However, those direct economic benefits are shared, primarily, between seed companies/developers and farmers and, to a lower extent, consumers. Via a seed premium, farm level benefits form GM crops are shared between the seed company and the farmer. E.g., in the U.S. such a premium makes GM maize seeds between 20 to 29% more expensive than conventional maize seeds (Kalaitzandonakes et al., 2010). The distribution of the innovation's benefits can be very different between crops and also depends on the region and the prevailing regulation system (Fischer et al., 2015). Zilberman et al. (2015) reporte that seed companies gain between 20 to 70% of the economic surplus created by GM crops. According to Qaim (2009), the premium for HR traits in soybeans, cotton, and canola, sold on the U.S. market, is often of similar magnitude or sometimes even higher than the average cost reduction for farmer. In such situations, the seed developer captures the entire farmer's economic benefits, except the non-priced benefits from management simplification and time savings. In another empirical study, which also includes gains in benefits for consumers and the rest of the world (ROW) Falck-Zepeda et al. (2000) analyze the introduction of Bt cotton in the U.S.. According to their model of a large open economy, from the entire welfare increase of 240.3 million USD in 1996, 59% stayed with U.S. farmers, 26% was captured by the seed company, 9% by U.S. consumers, and 6% by the ROW.

The distribution of gains of innovations is important for the diffusion of innovations and as an incentive for further R&D activities. While a farmer will adopt a technology if it increases his utility, the seed developer needs to generate a return on investment (ROI). To guarantee the benefits for the innovation's developer intellectual property rights are important (see *Section 3.4.1*).

Since only generation I GM crops are currently commercialized mainly seed developers and farmers directly benefit from this technology. While farmers represent only 1 to 2% of the society in developed countries, in developing countries around 60% of the society generates its income from primary agriculture. Especially the small and poor farmers in developing countries with low yields can benefit from GM technology (Sanglestsawai et al., 2014). However, in developed countries consumers, as the society's majority, tend to receive little direct benefit but are often concerned about potential negative irreversible health and environmental impacts.

3.4.1 Seed developer and market concentration

The development of GM innovations since the early 1990s coincided with an ongoing market concentration in the seed market. Through various mergers and acquisitions, large multinational pharmaceutical and agro-chemical companies from the U.S. and Europe invested in biotechnology know-how, access to seed germplasm, intellectual property rights (IPRs) and plant varieties (Cowan, 2010, Kalaitzandonakes et al., 2010, Moss, 2009). As one result, the number of influential independent seed companies decreased. While in 1996 the top nine seed companies had a share of 16.7% of the global seeds markets and only one of them was owned by a multinational agro-chemical company, in 2009 the top nine seed companies had a share of more than 40% of the global seed markets and five of them were associated with agro-chemical multinationals. From 1996 to 2006 only two of the top nine seed companies from 1996 remained independent. During the same period the annual sales value of the global seeds markets increased from 18 billion USD to about 44 billion USD (Schenkelaars et al., 2011). Thus, the global seed market did not just become more concentrated, but also more economically attractive. In such a market development it is not surprising that firms invest in M&A and R&D in order to achieve or maintain a leading position. Kalaitzandonakes et al. (2010) used the Herfindahl-Hirschman Index to analyze the market concentration in the U.S. seed industry for the years 1992 to 2008. For each year they find a value close to 1800 which is seen as the threshold between ‘moderately concentrated’ and ‘concentrated’.

Most recently M&As between the biggest six seed and agro-chemical companies have been announced. Thus, the development of market concentration is likely to continue. DuPont and Dow will combine in an all-stock merger. The merged company, named DowDuPont, will have a combined market capitalization of approximately 130 billion USD (DOW, 2016). Further, Bayer’s offer to takeover Monsanto for ca. 66 billion EUR was accepted (Bayer, 2016). It will be the most expensive M&A deal for a German company taking over a foreign company (Reuters, 2016).

Besides *direct* market concentration due to business acquisitions, research operations between different dominant firms represents an *indirect* form of market concentration. The latter is especially present in the GM seed market due to many different interdependencies in different forms of licensing. Each of the six biggest seed companies has different research cooperations with at least three other seed companies of this group (Howard, 2013).

The entry of large firms and an ongoing market concentration raises concerns that the entrance burden for new firms will increase and that incumbent firms will exercise market power when pricing their innovations. Increasing prices would affect the magnitude and distribution of resulting welfare gains (Alexander and Goodhue, 2002). In economic theory increasing market power comes along with higher relative shares of producers’ rents and relative lower shares of consumer rents. But increasing market power and emerging oligopoly market structure might even offer benefits to farmers and societies as the additional monopoly benefits economically justify higher private R&D expenditures. In general, high R&D expenditures for seeds are societally desired as it supports innovations, which are important for a sustainable agricultural production. As Fudenberg et al. (1983) explain, a company’s R&D investment decisions have the aim to ensure final payoffs. High market prices in concentrated oligopoly markets can lead to those necessary payoffs and justify high R&D investment. However, in a strong competitive market, single companies are less likely to invest. Following this line of argumentation, it is unlikely that a competitive seed market elicits R&D investments as high as under monopoly conditions.

Reasons for market concentration

M&As within the seed industry are driven by factors which are common to all industries (e.g. economies of scale and scope) and some of which are specifically tied to the seed industry. One factor driving market concentration is the general industry development. Especially agro-chemical multinationals determine the market concentration development. Firstly, they have the financial resources to invest in R&D of GM seed. Secondly, the agro-chemical sector matured (CHATAWAY et al., 2004). In fact, the developments of generation I GM crops focuses on crop production costs savings by reducing agro-chemicals input, at least in the case of IR crops. Thus, one can say that the agro-chemical sector reacted to the trend that farmer's expenditures on crop production inputs moved from agro-chemicals to seeds. The development of HR GM crops, also known as Roundup Ready crops, further offers the possibility to sell an agro-chemical-seed packages to the farmer. This way companies could benefit from product complementarity (FULTON and GIANNAKAS, 2002) and increase market power in both segments. Another factor driving market concentration is the R&D process of GM crops including regulatory costs, R&D costs, and intellectual property rights (IPR) (KALAITZANDONAKES et al., 2006). This is also confirmed by SCHENKELAARS et al. (2011) who interviewed eleven top executives from leading seed company about the reasons for market concentration within the seed sector. Their study determines *increases in plant breeding R&D costs* and *regulatory requirements for GMOs* as the main drivers for market concentration.

Intellectual property rights

To guarantee ROI from an innovation, intellectual property rights (IPRs) play an important role. They can also help to explain market concentration and recent M&A activities within the seed market. IPRs, such as plant breeds rights (PBRs) or patents were introduced in the 1970s. PBRs protect a new variety as a breeder's intellectual property and include exclusive sales rights. A new variety must meet certain criteria such as distinctness, uniformity, and stability. The method used to develop the variety is not protected by PBR (SCHENKELAARS et al., 2011). PBRs further regulate that other breeders can use the protected variety for research and the development of new varieties. In Germany, farmers can save the seeds from protected varieties but are obliged to announce how much land they will cultivate with those home saved seeds. For this area, the farmer must pay a re-seeding fee to a central body, which will distribute the money among breeders. IPRs in form of patents protect parts of the breeding process rather than the variety itself. The protection includes certain breeding steps such as certain hybridization techniques (conventional breeding) or techniques to introduce GM traits into the crops' genomes. Further, certain events can be protected by patents. All patent applications need to fulfill typical patent criteria including novelty, non-obviousness, inventiveness, and utility. With a patent, other parties are excluded from the use of the patented process or the sale of the patented product without the permission from the patent holder.

The *Patent Race (FUDENBERG et al., 1983)* gives an economic framework to explain market development under the influence of IPRs. With the introduction of GM technology patents became more important for the development of new traits. Within a *Patent Race* the firm that invests first leads the race and increases its chances of winning. A follower may not even want to participate in a race s/he is unlikely to win. However, since there are various, and not a one-time, protectable innovations in plant breeding competition will remain. Nonetheless, patent law may exclude competitors from the market in the short term and supports temporary monopolistic market structures. For a company which pursues complex biotechnological product development, there are incentives to be endowed with large and diverse arrays of IPR. Those incentives include, besides a monopolistic or market position, planning security and lower licensing cost for needed intellectually protected technologies (GRAFF et al., 2003). Furthermore, IPRs ensure returns on, and by that support, private investment in plant breeding research. Therefore, they promote the discovery and the development of new product inventions with substantial utility in the long term. Thus, there is a regulative trade-off between patent law and anti-trust regulation in finding the optimal solution between a competitive market—low consumer prices—and innovation incentives. Eventually, the temporary monopoly rents of the dominant firm from pricing above marginal cost might be an acceptable price for society to pay, in order to encourage innovations leading to incremental social benefits in the long run (SCHUMPETER, 2013).

3.4.2 Farm level effects

Despite widespread adoption of GM crops in many countries, the controversial discussion about their advantages and disadvantages continues. The first wave of GM crops to be commercialized (generation I) has embodied traits intended to reduce or eliminate losses from insect damage (IR crops) and to improve weed management systems (HR crops). Both technologies do not necessarily increase the crop's yield potential, but rather simplify its management. Thus, farm level productivities of generation I GM crops are mainly driven by crop stability, which may lead to yield increases, and cost reduction.

Different studies compare farm level effects from GM crop to conventional crop cultivation. The effects differ according to prevailing national cultivation systems, agronomic conditions and the farmer's economic situation (BENNETT et al., 2013, QAIM, 2009). Overall the majority of the literature, e.g. Barrows et al. (2014a), Bennett et al. (2013), Brookes and Barfoot (2014), Demont and Tollens (2004), Fernandez-Cornejo and Li (2005), Finger et al. (2011), Qaim (2009), Qaim and Traxler (2005), Scatasta et al. (2006), Wesseler et al. (2007), Zilberman et al. (2015), and Zilberman et al. (2010), suggests increasing farm level profitability due to reduced pest damage, increased yield, reduction in insecticide usage, and simplifications in farm management or time saving. A meta-analysis with 147 peer-reviewed journal articles by Klümper and Qaim (2014) leads to the result that on average, GM technology has reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68%. Further, yield and profit gains are higher in developing countries than in developed countries.

Barrows et al. (2014b) statistically investigated global total outputs of GM cotton, maize, and soybeans in different countries between 1996 and 2010. They find an average yield increase due to GM seeds in cotton and maize by 34% and 32%, respectively, relative to conventional seeds. However, in soybeans relative average yield increased only little with GM technology but overall production did increase by about 60%. Sexton and Zilberman (2011) find yield gains from GM crops up to 65% for GM cotton and up to 12.4% for GM soybeans. With a focus on yield increases Carpenter (2011) analyzes 168 results of the peer-reviewed literature comparing GM and conventional crops. Of these results 124 show positive, 32 no, and 13 negative yield effects from GM varieties. Again, the study, which considers 12 countries, suggests that mostly small farms in developing countries benefit from GM technology. The average yield increases for developing countries ranged from 16% for IR maize to 30% for IR cotton. Compared to this, cotton farmers in developed countries experienced on average only 7% yield increase from GM IR cotton. In terms of profitability, Carpenter (2011) surveyed 98 results of the peer-reviewed literature that compare the economic performance of GM crops to their conventional counterparts. Out of these, 71 results indicate a positive impact, 11 neutral, and 16 negative impact from GM crops on the farms' economic performances.

Increasing profitability of GM crops can improve farmers' income and reduce poverty. But as the cultivation of IR crops aims to reduce pesticide usage, it can also benefit the farmers' health conditions. Qaim and Kouser (2013) show that farms adopting IR cotton in India raised their income, leading to increased calorie consumption, during the period from 2002 to 2008. Also, from the adoption of IR cotton in India, the same authors reveal that the incidence of acute pesticide posing famers where reduced (Kouser and Qaim, 2011). The study by Ali and Abdulai (2010) delivers similar results for the adoption of IR cotton in Pakistan. They find a positive and significant impact from IR cotton production on yields, household income and poverty reduction, and a negative effect on the use of pesticides. Further results indicating improved farmers' health due to reduced exposure to pesticide, are derived by Bennett et al. (2006) for IR cotton in South Africa and by Huang et al. (2005)

and TAN et al. (2011) for IR rice in China. Health hazards from pesticides application are greater in developing countries as pesticides are applied manually, and farmers are less educated and less informed about negative side effects. BENNETT et al. (2004) also reporte negative health consequences as some farmers in South Africa mentioned that they developed allergies after planting IR cotton.

Even though developing countries could especially benefit from GM crop innovations, seed companies develop their GM crops rather for the demands of large capital intensive farms in order to generate high ROI (FISCHER et al., 2015, RAO and DEV, 2009). Thus, especially for farmers in developing countries there is a threat that developed GM seeds will be less suitable for their general regional growing conditions.

The adoption of GM crops at farm level comes along with different challenges including coexistence measurements and resistance building due to long term application.

Coexistence

Under current European law, GM crops are seen as substantially different compared to conventional crops even if they are approved for cultivation. This implies a challenge in the *coexistence* of GM crop farmers and their conventional farming neighbors, as well as in the *coexistence* of GM and conventional farm products along the supply chain. Different coexistence measures, such as minimum distance to neighboring farmers or storage restrictions after harvest, need to be taken to avoid adventitious presence of GM crops in conventional farm products.

The European Commission Decision 2005/463/EC from 2005 announced to establish a network group for the exchange and coordination of information concerning coexistence of GM, conventional, and organic crops (EUROPEAN UNION, 2010). Based on this initiative different EU member states developed national coexistence guide lines based on EU recommendations.

Coexistence measures will impact the farmer's production decision since they cause additional costs. Further, neighboring farmers, with their production decision concerning GM or non-GM production, will influence each other. There will be no coexistence costs for a GM farmer, if his neighbors produce GM crops as well and very high coexistence cost if all neighbors cultivate conventional crops (BECKMANN et al., 2010). Consequently, the individual farm production decision might cause a domino effect in a regional production pattern as described by DEMONT et al. (2008). Further, also coexistence measures at different production stages in other countries will deter the adoption of GM crops (BENNETT et al., 2013).

Development of resistance

One threat to long term farm level benefits are potential resistance of pests to the Bt enzyme (IR crops) and of weeds to glyphosate (HR crops). Both resistances would impair the functionality of the respective production systems. Several studies already report about occurring weed resistance against glyphosate (Cerdeira and Duke, 2006, Green, 2007, Powles and Yu, 2010). The development of resistances towards herbicides and other agro-chemicals over time is a general problem also for conventional non-GM crop production. However, GM crop production could be especially affected since they often depend on very specific modes of action.

Tabashnik et al. (2008) reveal that resistance to Bt increased substantially only in one out of six major pests in Australia, China, Spain, and the U.S.. To slow down resistance buildings in IR crops one strategy is to provide refuge areas with plants, which do not carry an IR trait. However, this strategy is critically discussed (Liu et al., 1999). Another strategy is the usage of different Bt toxins (Soberón et al., 2007). Therefore, seed companies develop stacked GM varieties, which produce different types of the Bt enzyme.

3.4.3 Effects on the environment

About 12% of the world's surface—more than 1.5 billion ha—is used for crop production (Alexandratos and Bruinsma, 2012). The expansion of this area, as a key input factor, is very limited. As more food needs to be produced with this scarce resource in order to meet the growing demand for food and feed, a relative production increase is necessary. At the same time, it is crucial to establish sustainable crop production systems to save this resource and maintain its fertility. Therefore, agricultural production must use less intensive agro-chemical and limit its impact on natural habitats and their biodiversity. Thereby, crop innovations can have an impact and guide agricultural production to a more sustainable future. Extensive field studies over the last 14 years showed that GM crops can help to make food production more sustainable when integrated with optimal management practices (Carpenter, 2010). In the following, different dimensions of GM crops innovations on the environment are discussed.

Agro-Chemical usage

The focus of input traits (generation I) are simplification and cost reduction in crop management, which

The focus of input traits (generation I) are simplification and cost reduction in crop management, which does not necessarily imply a reduction in agro-chemicals. In general, compared to conventional varieties, GM IR and GM HR crops require less and more agro-chemicals, respectively. Benbrook (2012) determines that IR GM crops have reduced insecticide application by 56 million kg and HR GM crops led to a 239 million kg increase in herbicide use in the U.S. between 1996 and 2011.

Glyphosate, an agro-chemical which is directly linked to HR GM crop cultivation is controversially discussed. On the one hand, the absolute usage of glyphosate increased together with the increasing cultivation of HR GM crops. The combination of HR GM seeds and glyphosate allowed an expansion of agricultural cultivation area especially in South America, which led to a partly distortion of natural habits, biodiversity, and resources (PENGUE, 2005, PHALAN et al., 2013). On the other hand, the broad-spectrum herbicides glyphosate does have a lower environmental impact[6] than alternative selective herbicides such as imazethapyr and chlorimuron (BROOKES and BARFOOT, 2014). Also, no-tillage cultivation systems which are possible in HR cultivation systems can reduce greenhouse gas (GHG) emission, fuel use, and soil erosion and increase soil fertility, soil water conditions, crop yields, and biodiversity compared to conventional tillage systems (AMMANN, 2005, BLANCO-CANQUI and LAL, 2008, CARPENTER, 2011, QAIM and TRAXLER, 2005, SMITH et al., 2007).

In cotton, the crop with the highest relative pesticide demand, the introduction of GM IR varieties led to a significant reduction of agro-chemical (BENNETT et al., 2013). BROOKES and BARFOOT (2014) estimate that between 1996 and 2006 IR cotton was responsible for global savings of 205.4 million kg of pesticide active ingredients, reducing the environmental impact of total cotton pesticides by 28.2%.

GHG (CO2) emissions

GM crops can potentially reduce CO_2 emissions due to a reduction of mechanical field work and its associated fuel usage. That is because GM IR cultivation systems demand lass spraying and GM HR crops facilitate the possibility of no-tillage (or reduced tillage) farming systems. Depending on the crop and region, no-tillage systems can save about 50% of the fuel used for cultivation (BROOKES and BARFOOT, 2014). Furthermore, no-tillage farming is superior to intensive tillage, such as plow tillage, for its potential to sequestering soil organic carbon (SOC) (BLANCO-CANQUI and LAL, 2008). In a meta-analysis ANGERS and ERIKSEN-HAMEL (2008) come to the conclusion that on average additional 4.9 t SOC/ha are stored under no-tillage compared to under intensive tillage systems. It is important to mention, that no-tillage systems cannot be run within a crop rotation system. Still, under crop rotation reduced tillage can be facilitated by HR crops. In the *Empirical Study 3,* we determine that HR rapeseed production under reduced tillage cultivation saves 23% or 160.89 kg CO_2 equivalent/ha/a compared to conventional cultivation (IFEU, 2015).

Biodiversity

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[6] Environmental impact measured by the Environmental Impact Quotient (EIQ)

On the one hand, as mentioned earlier, GM crops can negatively impact biodiversity since they drive the expansion of agricultural cultivation area. On the other hand, if compared to conventional farmed land, GM crops can change biodiversity in different ways. First, the widespread cultivation of GM IR crops could decrease insect biodiversity by nontarget effects of the Bt enzyme. Second, GM HR crops could decrease the availability of weeds as food for seed-eating birds. Third, the adoption of just a few GM crop varieties could result in the narrowing of genetic diversity of the crop itself (BENNETT et al., 2013).

One of the largest studies that compared adverse effects of weed management in GM HR and conventional crops was carried out in the UK from 2000 to 2003. The study involved 266 field trails and four GM HR crops; beet (sugar and fodder beet), maize, and both winter and spring-sown rapeseeds. The study could not find evidence that GM crops and the corresponding management practice affect invertebrates[7] different than conventional farming practice (DEWAR et al., 2005). Concerning the effect of GM IR cotton and maize on non-target invertebrates MARVIER et al. (2007) conducted a meta-analysis of 42 field experiments. They find that invertebrates are generally more abundant in GM IR cotton and GM IR maize fields than in fields managed with conventional seeds and insecticide application. However, compared to conventional insecticide-free control fields, certain non-target taxa are less abundant in GM IR fields. Overall, compared to conventional cultivation, GM crop cultivation is likely to support biodiversity on the field where it is grown (AMMANN, 2005). However, due to conversion of natural habits into farm land and also due to less variety in crops and production systems, biodiversity can be negatively affected.

Cross pollination and gene transfer

Genetic information from GM crops can transfer to other living organism *vertically* and *horizontally*. *Vertical gene transfer* is the transmission of genetic information from parent to offspring. A GM plant might produce offspring not just with its own variety but also with non-GM crops or wild relatives. That kind of *vertical gene transfer* is of potential concern because it could facilitate the development of new weeds. If such new weeds are also HR, it could be difficult to control them in fields (KEY and SNEERINGER, 2014). However, such new weeds are unlikely to have an advantage in ecosystems not controlled by herbicides. Other characteristics such as IR or drought resistance might be a bigger threat to natural ecosystems since they could cause competitive advantage towards other wild life species. Furthermore, *vertical gene transfer* could negatively affect conventional and especially organic farms. Their products could not be sold as non-GM and organic farms might even lose their

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[7] The group of invertebrates includes besides insects also worm, slugs and snails.

organic status. *Horizontal gene transfer* is the transmission of genetic information to organism of different species. This might affect important micro-organisms in the soil (CONNER et al., 2003).

Ways to prevent unintended gene flow, and guarantee coexistence, include physical isolation and genetic containment (KEY et al., 2008). Physical isolation requires coordination of production sides between farms, which might be costly and does not guarantee no contamination (VENUS et al., 2016). Genetic containment can be achieved by sterility and incompatibility systems, such as Genetic Use Restriction Technologies (GURTS), which interfere with fertility or seed formation (KEY et al., 2008).

Resource usage

Generation III GM crop, which produce inputs for industrial usage offer the possibility for a more sustainable resource usage. Non-renewable resources, such as crude oil, could be replaced with plants as renewable resources. For example, the GM potato Amflora was designed to produce starch consisting out of amylopectin and not of a mixture of amylopectin and amylose as starch from conventional potatoes. This characteristic facilitates the industrial usage of potatoes as a renewable and biodegradable resource (RYFFEL, 2010). But despite its advantages and its successful approval by the EU, the Amflora potato was never introduced to the commercial market.

3.4.4 Effects on the consumer

GM technology can affect consumers by price changes due to the previous mentioned aspects such as market power of seed companies, farmers' productivity, food quality, and environmental impacts.

In general, consumers are likely to benefit from innovations in crop production, since lower production costs, yield increase and crop stability eventually affect the market price for food. Low and stable food prices are especially beneficial to consumers in developing countries, who spend 50% or more of their income on food consumption. Those consumers operate on a very inelastic part of the demand function and are very sensitive to price volatility, which may also be driven by scarcity in food products (WRIGHT, 2011).

Besides food quantity, food quality also plays an important role for human health. Undernourishment due to lack of calories, protein, or micronutrients remains a major concern in many developing countries. Lacks of micronutrients are especially present, where people rely on one single staple food crop for their energy intake. Deficiency in Vitamin A or Fe and Zn causes severe problems for human health and belongs to the most severe diseases for humankind (COPENHAGEN CONSENSUS CENTER, 2016). The World Health Organization (WHO) estimates that 250 million preschool children and a substantial proportion of pregnant women in jeopardized areas are vitamin A deficient. Further, it is estimated that 250,000 to 500,000 children go blind due to vitamin A deficiency every year and about half of them die within 12 months (WHO, 2016). Biofortification of staple food crops by biotechnological—generation II (see *Section 3.3.2*)—and conventional plant breeding could play an important role to fight those diseases in the future. As the most famous examples, Golden Rice was designed to fight Vitamin A deficit. According to DE STEUR et al. (2015) Golden Rice has the potential to lower the burden of vitamin A deficiency in China, India and, the Philippines. Nevertheless, Golden Rice is not commercially available in any country, yet.

Safety risks for the consumer

Currently available food products from GM crops (generation I) are controversially discussed concerning their health implications. For more than 15 years GM crops are fed to animals and food products from GM crops are consumed by humans. GM crops are usually not directly consumed by humans. It’s rather their manufactured products, such as oil from soybeans or sugar from sugar beets, which are part of the human diet. Similar to conventional food products there are risks that GM food crops might cause allergens or food intolerances. However, different to conventional crops, GM crops undergo extensive safety testing prior to commercialization (see *Section 3.2.1*). So far no empirical case of negative health effects directly linked to consumption of GM crops, neither as feed nor as food, was ever reported (KEY et al., 2008).

EWEN and PUSZTAI (1999) claimed that rats fed with GM potatoes, expressing the gene for the lectin Galanthus nivalis agglutinin, suffered damage to gut mucosa. However, the Royal society stated that, due to flaws in many aspects of the design, execution, and analysis, no conclusions should be drawn from this study (KEY et al., 2008). SÉRALINI et al. (2012) report negative health effects for rats after consuming GM maize, cultivated with and without glyphosate (Roundup), for two years. The study was also highly criticized for their conclusion drawn from their experimental set up (PANCHIN, 2013). Eventually, the publishing journal retracted the study in November 2013 (HAYES, 2014). Other studies such as CARMAN et al. (2013) find no health impact from feeding GM crops. WU (2006) shows even that GM IR maize contains lower levels of health-damaging mycotoxins, which would be caused by insect damages. Thus, GM IR maize could help to increase fodder quality and thereby animal health. Furthermore, latest extensive reviews from BENNETT et al. (2013) and DOMINGO (2016) find no support for adverse effects of GM crops on human and animal health. Nevertheless, uncertainty about long term health hazard remains (DEFRANCESCO, 2013).

3.5 Acceptance of GM crops

GM crops are probably the most controversial discussed innovation in modern agriculture. In the previous sections various effects associated with GM crops are discussed. Overall, studies such as BENNETT et al. (2013), DALE et al. (2002) ,DEFRANCESCO (2013), DOMINGO (2016), EUROPEAN ACADEMIES

Science Advisory Council (2013), European Commission (2010b), Fagerström et al. (2012) conclude that GM crops do not per se offer higher risk to environment and human health than conventional crops. The same opinion is shared by most academic associations such as the British Royal Society, the French Académie des Sciences and the German Akademien der Wissenschaften. Further, as mentioned in *Section 3.4.3* and *3.4.4* there are even potential benefits to human health and the environment reported. On the other side, potential negative effects cause a general negative consumer attitude towards GM crops in many regions of the world. The rejective attitude of societies towards GM crops is based on a variety of (ethical) concern including: potential harm to human health; potential damage to the environment; negative impact on traditional farming practice; excessive corporate dominance; and the 'unnaturalness' of the technology (Weale, 2010).

According to the Eurobarometer for Biotechnology 2010, 57% European (EU 25) citizens are not willing to support GM foods (Gaskell et al., 2010). In Germany, 70% of the citizens see *no application of GM technology in food* as *absolutely necessary/ very important* according to a survey by forsa (2014). In one specific example for Germany Hartl and Herrmann (2009) report that 74% of their respondents neglected GM rapeseed oil. Gaskell et al. (2004) explain the rejection of GM foods and crops by the European public is not so much based on the perception of risks as on the absence of benefits. However, generation II traits are more likely to be accepted at lease by German society (Hartl and Herrmann, 2009). Grunert et al. (2003) find that the attitude of German consumers towards GM food can be characterized as top-down processing. Those attitudes are derived from more general attitudes which are deeply rooted. It is therefore unlikely that these prior attitudes can be easily influenced or changed by providing additional information.

Consumer attitudes towards GM crops differ between regions. The variation in the level of acceptance among consumers might be explained by cultural aspects, differences in public debates and economic development (Springer et al., 2002). In general, U.S. consumers are more receptive to GM products than European consumers (House et al., 2005, Huffman and Rousu, 2006). McCluskey et al. (2006) compare willingness to pay (WTP) for GM crops based food in Japan, Norway, Canada, U.S., and China. Except in China, consumers evaluated non-GM higher than GM based food. In Japan and Norway, consumer would be willing to purchase GM based food only on a ca. 50% discount. In Canada and the U.S., the discount would need to be ca. 25% and Chinese consumer were found to be willing to pay a premium of 38%. González et al. (2009) find a positive WTP—60-70% above market price—for biofortified cassava in the Northeast of Brazil. For Golden Rice Lusk (2003) and Depositario et al. (2009) determine a positive average WTP of 21% in the Philippines. The reasons for the general rejection and regional differences are often less based on factual knowledge about biotechnology, but rather on social influence of different stakeholders. According to a literature analysis by Ponti

(2005), in the European discussion about concerns of GMOs, technical and scientific arguments are often mixed up with more general social issues such as globalization, American hegemony, economic concentration, and the increasing dependence of agriculture on technology. In this context, non-governmental organizations (NGOs) or social movement organizations (SMOs) (ANDRÉE, 2011) and lobby groups (FAGERSTRÖM et al., 2012) have a crucial importance. Influenced by them, the media, citizens, elected officials, and some farmers' associations have become highly critical of the seed industry, in particular of the largest seed companies (BONNY, 2014). NGOs or SMOs present themselves as representatives of consumer interests and due to their non-profitable character, they usually have a high level of trust within the society compared to regulators and industries. Nevertheless, these groups strive for founding and political influence. In that sense it is important to mention, that the anti-GM campaigns have been successful fundraising strategies for NGOs in the past (APEL, 2010).

Various individual aspects, such as knowledge or education etc., can affect individual attitudes towards GM crops. However, the direction of the effect is not clearly identified. For example, for the relationship between higher objective knowledge about GM technology and an increasing support for the application of GM crops VERDURME and VIAENE (2003) find a positive, SPRINGER et al. (2002) a negative and HOUSE et al. (2005) no relationship. Similarly, the effect of education is also not clearly identified (GRIMSRUD et al., 2004, ONYANGO and NAYGA JR, 2004). Furthermore, MCFADDEN and LUSK (2015) point out that the assimilation of scientific information about GM foods is dependent on prior beliefs. Eventually, the formation of a consumer attitudes towards GM crops remains a complex and interdisciplinary topic.

4 Methodological overview

The literature body for the assessment of agricultural innovations is large in methodological frameworks and empirical applications. QAIM (2009) classifies economic analyses about GM crops into micro- and macro-approaches. Micro-approaches are associated with private farm-level effects, while macro-approaches focus on welfare effects for societies on country, region or global level. Further, both approaches can be distinguished into ex-post and ex-ante, depending on the time perspective.

This section outlines the methodologies applied in the following empirical studies. For the analysis in the *Empirical Study 1* information from literature and other sources were gathered to prepare a case study. In the *Empirical Studies 2* to *5* three different economic concepts are applied. In the *Empirical Study 2*, global price relationships are analyzed using cointegration analyses; in the *Empirical Studies 3* and *4*, maximum incremental social irreversible costs (MISTICs) are determined applying a real options approach; and in the *Empirical Study 5* marginal shadow values are determined based on a stochastic distance frontier approach. The core of the methodological approaches in the *Empirical Studies 2, 3, 4,* and *5* is also explained within the studies, but a broader introduction and some supplementary information is provided in this section.

4.1 Methodological concepts of Cointegration

The research framework used for the cointegration analysis in the *Empirical Study 2* is a very specific design for the addressed research question. In general, the concept of cointegration is a well-established methodology in financial (JOHANSEN and JUSELIUS, 1990, NEIL MYER et al., 1997) and agricultural economics (BAEK and KOO, 2006, BARASSI and GHOSHRAY, 2007, GHOSHRAY, 2007, GOYCHUK and MEYERS, 2011) time series analysis. Nevertheless, a similar group testing structure, as in the *Empirical Study 2*, in order to describe market reaction after a certain event is rarely applied. LEHECKA (2013) use a similar methodological framework to analyze the relationship between food and financial market.

4.2 Methodological concepts of real options and MISTICs

The *Empirical Studies 3* and *4* use a research design building upon real options (RO) theory. RO theory was developed out of financial-option theories by MCDONALD and SIEGEL (1986), DIXIT and PINDYCK

(1994), and SCHWARTZ and TRIGEORGIS (2004). Further RO theory is based on the theory of price formation in efficient financial markets (SLADE, 2001).

WESSELER and LAXMINARAYAN (2003) suggest the empirical application of RO theory to conduct ex-ante cost-benefits analyses and assess potential future effects from GM crops accounting for reversible and irreversible, private and social costs and benefits. DEMONT et al. (2004) and WESSELER et al. (2007) empirically apply the methodological framework to analyze socio-economic consequences from introducing GM sugar beets and GM maize in Europe, respectively. The methodological framework established as MISTICs (maximum incremental social irreversible costs).

In another empirical application of a RO approach, WILSON et al. (2015) estimate the value of GM drought tolerance wheat for the U.S. market. In a similar manner, SHAKYA et al. (2012) and SHAKYA et al. (2013) assess economic potential for GM HR wheat and different GM traits in maize, respectively, for different American regions. With a focus on health aspects, RO theory is applied to estimate the socio-economic value of GM output traits such as Golden Rice in India (WESSELER and ZILBERMAN, 2014) or nutritionally enhanced bananas in Uganda (KIKULWE et al., 2008).

RO are an extension of the net present value (NPV), the traditional tool for an economic evaluation of an investment. The NPV of an investment project is the present value of its expected future cash flows (CFs). In a NPV calculation future CFs are discounted, using an interest rate (r), to the starting point of the investment ($t = 0$) and compared to its investment costs I.

$$NPV = \sum_{t=1}^{N} \frac{CF_t}{(1+r)^t} - I \tag{1}$$

A positive NPV, meaning that the discounted future CFs exceeds I, suggests to invest. However, the NPV does not account for uncertainty, irreversibility, and flexibility—the option to postpone—of an investment. To overcome the restriction of a NPV calculations MCDONALD and SIEGEL (1986) and DIXIT and PINDYCK (1994) propose the model of RO as a strategic decision making tool. The RO concept transfers the idea of value determination for a financial call option at the stock market to real investment projects. More precisely, it is analogous to a perpetual call option on a dividend-paying stock (DIXIT and PINDYCK, 1994: 157). Meaning, the holder of an option has the right, but not the obligation, to acquire a certain asset (financial call option (FCO)) or to do a certain investment (RO) at predetermined price. The central idea is that during the course of time, or by waiting, uncertainty about costs and benefits of an irreversible investment will reduce since more information will arrive. Thus, a RO approach is of particular importance if aspects of an innovations, such as the adoption process or its private and social payoff, are accompanied by irreversible costs. If all costs that accompany an investment decision would be reversible, there would be no incentive to postpone the investment (provided that the benefits exceed the costs of the investment), even if future benefits and costs are uncertain. Thus, irreversibility of an investment is an important characteristic, which in general reduces the benefits of a possible investment (ARROW and FISHER, 1974). Consequently, the presence of irreversibility gives a value to the possibility to postpone the decision and to wait for the arrival of more information about the innovation's risk.

MCDONALD and SIEGEL (1986) specify the characteristics that an investment needs in order to be treated as a RO:

- The underlying asset pays a continuous dividend yield
- The development of the underlying asset follows a geometric Browian motion (GBM)
- The underlying asset is the only stochastic variable
- The lifetime of the option is infinite
- One can exercise the option at any point in time
- There is no interaction with other options

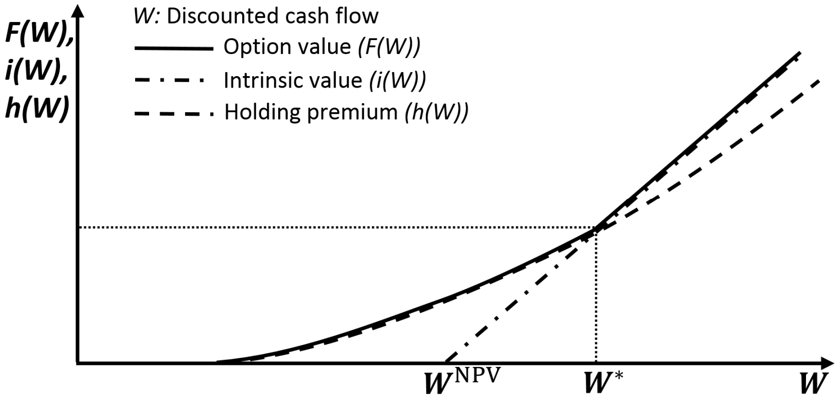
(MUßHOFF and HIRSCHAUER, 2003: 135)

The economic benefits of holding an investment option can be referred to as the holding premium, which one must expect to pay to secure the option and maintain the flexibility of the decision (ANDOSEH et al., 2014). The option value accounts for the holding premium, the intrinsic value of the underlying asset and its uncertain volatile price (for a FCO) or CFs (for RO). If future costs and benefits are without uncertainty or not irreversible (purely reversible) the option of waiting has no value. This is plausible, in so far, that in both cases, there would be no incentive to postpone the investment (provided that the benefits exceed the costs of the investment) (MUßHOFF and HIRSCHAUER, 2003). It is important to consider that postponing an investment decision can cause costs of forgone benefits, which might have been generated if the investment was undertaken immediately. Similar to a dividend-paying stock, only the physical possession of the investment object generates CFs, which are denoted convenience yields (MUßHOFF and HIRSCHAUER, 2003). Discounted convenience yields and other economic benefits, such as market power from holding an asset, form the intrinsic value of the investment option. Eventually, an option should be exercised when the intrinsic value exceeds not only zero but the holding premium. Exercising in this context means that the owner of the option exchanges the right for ownership to actual ownership of an asset, under the predetermine conditions. In other words, the value of waiting is exchanged for the intrinsic value of the option. A RO can be exercised at any point in time, similar to an American type

FCO[8]. Different to FCO, RO and their underlying assets are typically not traded (ANDOSEH et al., 2014) and often perpetual.

Figure 4 graphically compares the optimal point to invest (W^*) using a RO approach with the discounted CFs (W), considering the value of the option value $\left(F(W)\right)$.

Figure 4: Optimal investment in a real options approach



Source: Author's own compilation based on MUßHOFF and HIRSCHAUER (2003) and DIXIT and PINDYCK (1994)

At W^{NPV} the NPV of an investment is zero. Consequently, W^{NPV} is the critical investment point in a NPV calculation, which indicates to invest as soon as the NPV, or the option's intrinsic value, is positive. The critical investment point under the RO calculation (W^*) is the intercept of the holding premium $\left(h(W)\right)$ with the intrinsic value $\left(i(W)\right)$, at which the slope of both functions is one. The shape of the option value $\left(F(W)\right)$ is characterized by the holding premium until W^*. After W^* $F(W)$ is similar to the slope of $i(W)$ since there will be no benefit in postponing the investment and the value of holding becomes zero. As depicted, W^* is a more restrictive investment criteria than W^{NPV} $\left(W^{\mathrm{NPV}} \leq W^*\right)$. Under RO assumptions, as long as W is below W^* the option's owner would wait for further information to arrive and may not exercise the option at all. The option would only be exercised if $W \geq W^*$. If volatility of future CFs are assumed to increase, W^* would move further to the right (*Figure 4*), indicating a higher value of waiting.

For a better understanding of the importance of the intrinsic value—convenience yield and other economic benefits—for exercising RO it is helpful to stress its analogy with a financial call option. If

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[8] Different to an American type FCO, a European type FCO can only be exercised by the end of the option period.

W were the price of a share of a dividend-paying stock, the total expected return on the stock would be the dividend rate plus the expected return from a price increase. If the dividend rate were zero, a call option on the stock would always be held to maturity, and never exercised prematurely. The reason is that the entire return on the stock is captured in its price movements. But if the dividend rate is positive, there are opportunity costs of keeping the option and not exercising it. This implies for ROs that if the convenience yield is zero, there would be no opportunity cost in keeping the option, and one would never invest, no matter how high the NPV of the project (DIXIT and PINDYCK, 1994).

4.2.1 Geometric Brownian motion (GBM)

The value of RO is very sensitive to the volatility of its underlying and the applied discount and drift rate. The volatility effect depends on the standard deviation of the past observations of the underlying asset and on the chosen stochastic process to predict future development of the investment's CFs. In general, the higher the probability of fluctuation in values, the more worthwhile it becomes to wait for future information. For the stochastic process we assume a geometric Brownian motion (GBM), which is a standard approach in RO theories (DIXIT and PINDYCK, 1994, MUßHOFF and HIRSCHAUER, 2003).

The GBM has some important properties according to DIXIT and PINDYCK (1994) and MUßHOFF and HIRSCHAUER (2003):

- It is a Markov process, i.e. the prediction of the following stochastic value only depends on the previous value.
- It counts for non-stationary[9] time series. Meaning that the expected values are not constant over time and that the variance of the price increases over time.
- It has independent increments. Meaning that the probability distribution for the change in the process over any time interval is independent of any other (non-overlapping) time interval.
- The changes in the process over any finite interval of time are normally distributed, with a variance that increases linearly with the time interval.
- It implies that the price constantly increases over time.
- It assumes that the prices can't be negative. Once the price is smaller than or equal to zero they will not turn positive again

Standardly, in RO theories the GBM is simplest generalized as a GBM with drift:

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[9] An example for a stationary process might be the development of temperature in Weihenstephan. The expected temperature value at July 28th might be the same every year with a constant variance over time (excluding impacts of global warming).

$$dx = \alpha dt + \sigma dz \tag{2}$$

with

$$dz = \varepsilon_t \sqrt{dt}, \varepsilon_t \approx N(0,1)$$

with the increment of a Wiener process (dz), a drift parameter (α) and the variance parameter (σ). ε_t is a normally distributed random variable with a mean of zero and a standard deviation of 1 and is assumed to be serially uncorrelated (SCHWARTZ and TRIGEORGIS, 2004: 240). *Equation 2* can be written as;

$$dx = a(x,t)dt + b(x,t)dz \tag{3}$$

With $a(x,t)$ and $b(x,t)$ as functions for the drift and variance coefficients, respectively, depending on the current value of the discounted CFs (x) and time (t).

4.2.2 Maximum Incremental Social Tolerable Irreversible Costs (MISTICs)

To solve for an option value that follows a GBM one can use dynamic programming or contingent claim analysis. DIXIT and PINDYCK (1994) showed that both lead to the same result. The shared result states that it is optimal to invest if W exceeds not only the investment's sunk costs but also the critical value W^* (see *Figure 4*), which can be derived by including uncertainty and irreversibility through the hurdle rate $\left(\frac{\beta}{(\beta-1)}\right)$;

$$W^* = \frac{\beta_1}{(\beta_1 - 1)}(I - J) \tag{4}$$

where I are social incremental irreversible costs and J are social incremental irreversible benefits. Since $\beta_1 > 1$, the hurdle rate will always be larger than 1 if insecurity exists ($\sigma > 0$). Thus, the net irreversible benefits $(I - J)$ are weighted more heavily than the net reversible benefits (W). Further, the hurdle rate—the weighting factor—increases with increasing volatility of past cash-flows since we assume that past volatility makes future returns more risky and uncertain (see *Section 4.2.3*).

We follow DEMONT et al. (2004) and WESSELER et al. (2007) to construct Maximum Incremental Social Tolerable Irreversible Costs (MISTICs). To do so we resolve *Equation 4* for I;

$$I^* = \frac{\beta - 1}{\beta} W + J \tag{5}$$

MISTICSs (I^*) are analogous to the irreversible investment costs (I) of a common RO approach. Thus, MISTICs identify an upper bound for incremental social irreversible costs from the introduction of an innovation, up to which the release of the new technology can be considered socio-economical.

The concept of MISTICs is applied in the *Empirical Studies 3* and *4*, where it is further explained. Further explanation on option values are especially provided in the *Empirical Study 3*.

4.2.3 Capital asset pricing model (CAPM)

The discount rates within the RO models in the *Empirical Studies 3 and 4* are derived using the capital asset pricing model (CAPM). The application of the CAPM requires a riskless rate of return (r) as exogenously given and the existence of a more general market for the evaluated asset. This means, that it must be possible to create a hedged market portfolio similar to the target asset, which captures the risk associated with the industry (COPELAND and COPELAND, 2003). In finance, usually a broad index of stock market prices such as the S&P 500 or DAX 30 is used as a market portfolio. In our case, for the assessment of crop innovations, the hedged market portfolio is constructed using the average gross margin of specialized crop farms per hectare in Germany. Thus, it is assumed that this margin will be achieved if crop farms which spread their risk by a diverse crop production. The relevant dataset is published by the German Federal Ministry of Food and Agriculture (BUNDESMINISTERIUM FÜR ERNÄHRUNG UND LANDWIRTSCHAFT, 2014).

The CAPM considers that an investor requires excess returns to compensate for any systematic risk associated with the industry (HULL, 1999). Formally, the CAPM based discount rate can be expressed as;

$$\mu = r + \lambda\sigma \tag{6}$$

where r is the risk-free rate, λ is the market price of risk for the considered industry and σ is the volatility of the considered asset (HULL, 1999).

The market price of risk (λ) can be estimates as;

$$\lambda = \frac{\rho}{\sigma_m}(\mu_m - r) \tag{7}$$

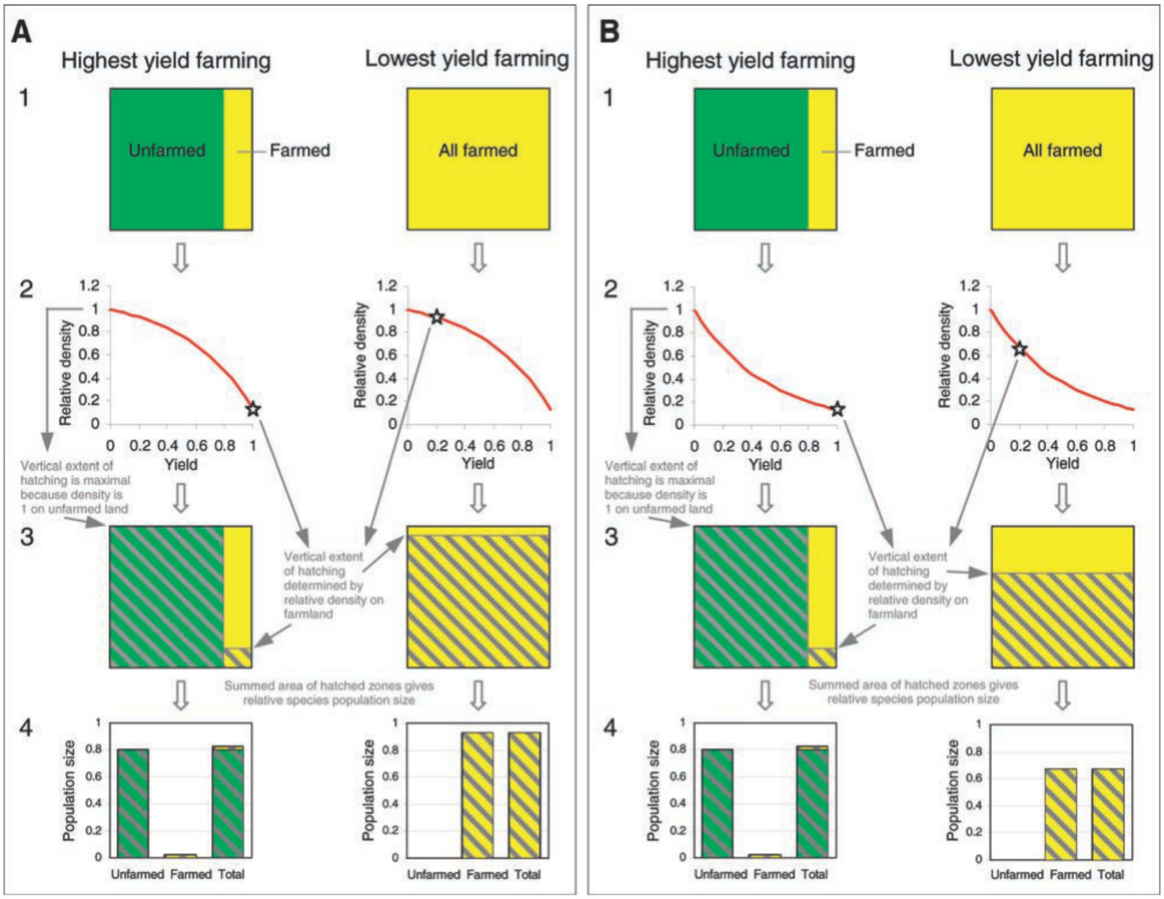
where ρ is the instantaneous correlation between the percentage changes in the investment asset and returns on a hedged market portfolio. From the hedged market portfolio one can collect the information on its expected return (μ_m) and volatility (σ_m) (HULL, 1999).

4.2.4 Decompensation Scenarios

In the *Empirical Study 4,* a decompensation scenario is introduced to show potential environmental benefits of a purely yield-increasing innovation in wheat production. In this section, the theory behind this idea is explained in more detail.

The idea is based on GREEN et al. (2005) who analyze two competing solutions for protecting birds and crop farming activities. One solution can be wildlife-friendly farming, which increases densities of wild populations on farmland but decrease agricultural yields. Another solution can be land sparing or decompensation zones, which minimize demand for farmland by increasing yield on the farmed area relative to wildlife-friendly farming. Green et al. (2005) present a model which identifies how to resolve the trade-off between these approaches and their findings show that the latter may allow more species to persist. However, the best type of farming for species persistence depends on the demand for agricultural products and on how the population densities of different species on farmland change with agricultural yield. Green et al. (2005) gave two examples for the environmental impact of highest and lowest yield farming (*Figure 5*).

Figure 5: Decompensation scenarios and wildlife density



Note: Two examples (A and B) explain the relationship of farming activities and wildlife population. The examples differ according to the relative density of wildlife and relative yield achieved on the farmed area. The target yield is 0.2.
Source: Green et al. (2005)

In *Figure 5*, two examples (A and B), which differ according to the relationship between relative density of wildlife and relative yield achieved on the farmed area, are presented. In both examples, the highest yield farming area is composed of farmed (yellow) and unfarmed (green) land, and another the lowest yield farming area is composed entirely of farmed land (yellow). In example A, the target agricultural production of 0.2 could be achieved by highest yield farming on 20% of the farmed land, leaving 80% of the area for a decompensation zone. Alternatively, the same target yield can be achieved by lowest yield farming on the entire area. It is assumed that the wildlife density is 1 on unfarmed land and that it decreases with higher yielding farming. On the land under highest yield farming the wildlife density reaches its lowest value. The total wildlife population is the sum of farmed and unfarmed land as depicted in the histogram in *Figure 5*.

In example A, with a *concave* relationship between relative density of wildlife and relative yield achieved on the farmed land, lowest yield farming leads to higher wildlife population than highest yield farming at equal outputs. In contrast, a *convex* relationship between relative density of wildlife and relative yield achieved on the farmed land, as in example B, highest yield farming leads to higher wildlife population than lowest yield farming at equal outputs. Thus, in example B land decompensation in combination with high yield farming is superior in terms of wildlife population or biodiversity. We follow this idea in the decompensation scenarios in the *Empirical Study 4*.

4.3 Methodological concept of Stochastic Frontier Analysis (SFA)

Stochastic frontier analysis (SFA), developed by FARRELL (1957), BATTESE and COELLI (1988), and KUMBHAKAR and LOVELL (2003) and others is generally designed to analyze input and output interactions in a production process. Different research question in agricultural economics, such as the importance of ecosystem services (SAUER and WOSSINK, 2013) and the productivity and technical efficiency of dairy (ABDULAI and TIETJE, 2007, BRÜMMER et al., 2002, FLEMING and LIEN, 2009, NEWMAN and MATTHEWS, 2006, SAUER and LATACZ-LOHMANN, 2015) and crop farms (AJIBEFUN, 2008, COELLI and FLEMING, 2004, PAUL and NEHRING, 2005, RAHMAN, 2009, RASMUSSEN, 2010, REZEK and PERRIN, 2004, SOLÍS et al., 2009) have been addressed with this approach. Further, SFA is used to describe shadow prices for negative farming externalities, such as pollution (ARANDIA and ALDANONDO-OCHOA, 2011, FÄRE et al., 2006).

SFA is based on production theory. In production theory, it is assumed that a technology describes the relationship between inputs and outputs for a certain production process. Within the given technology, producer, e.g. farms, use inputs to produce outputs. Some inputs and outputs might be exogenously given, others are likely to be chosen by the producers to maximize or minimize some objective function. This mentioned optimizing behavior makes input and output choices within a production process endogenous (KUMBHAKAR et al., 2013). An objective function might be costs function (cost minimizing behavior) or a profit or revenue function (profit or revenue maximization behavior). SFA can be facilitated by various functional forms for the production function, costs function and distance function (DF) (GREENE, 2008). DFs might be input or output oriented. Input-oriented DFs are in general more appropriate for the characterization of agricultural production process on farm-level (PAUL and NEHRING, 2005). In the *Empirical Study* 5, an input-oriented distance function (DF) is chosen to represent multi-output and multi-input technologies.

Given a technically feasible set (S^t), the input oriented DF measures for each observation the largest radial contraction of an input vector (x^t), given outputs (y^t) (FÄRE and PRIMONT, 1995). The mathematical representation of the optimization function is as follows;

$$D_{\mathrm{I}}{}^{t}(x^t, y^t) = \max_{\rho}\{\rho > 0 : (x^t/\rho) \in \mathrm{S}^t)\} \qquad (8)$$

This functional form measures the maximum scalar (denote as ρ), such that x^t/ρ remains in the feasible production technology set. The input oriented DF shows values larger than or equal to one $\left(D_{\mathrm{I}}{}^{t}(x^t, y^t) \geq 1\ if\ x^t \in \mathrm{S}^t\right)$ (GREENE, 2008). The value of the input oriented DF indicates the maximum possible reduction of the input vector under efficient production, holding the output level constant. A input oriented DF value of 1 indicates that the observation is part of the frontier of the production technology set S^t. In this case, there is no reduction potential of inputs. Values between 1 and infinity indicate production with a distance to the production frontier and by that technical inefficiency (COELLI and FLEMING, 2004). Increasing the efficiency of a farm corresponds to a larger ρ value, which implies that the observation is closer to the stochastic frontier. By definition $D_{\mathrm{I}}{}^{t}(x^t, y^t)$ is a non-decreasing, positively and linearly homogenous and concave in x^t and non-increasing in y^t (COELLI and FLEMING, 2004, SAUER et al., 2006).

Figure 6 illustrates the input DF for farms producing output (y) using two inputs (x_1 and x_2) assuming constant returns to scale[10] (x_x/y).

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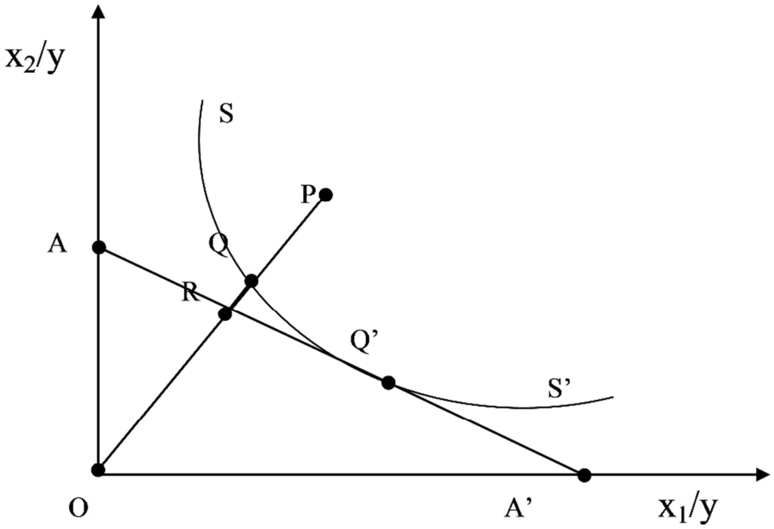
[10] The assumption of constant returns to scale allows the technology to be represented using a unit isoquant.

Figure 6: Input-oriented measure of technical and allocative efficiency



Source: Coelli et al. (2005)

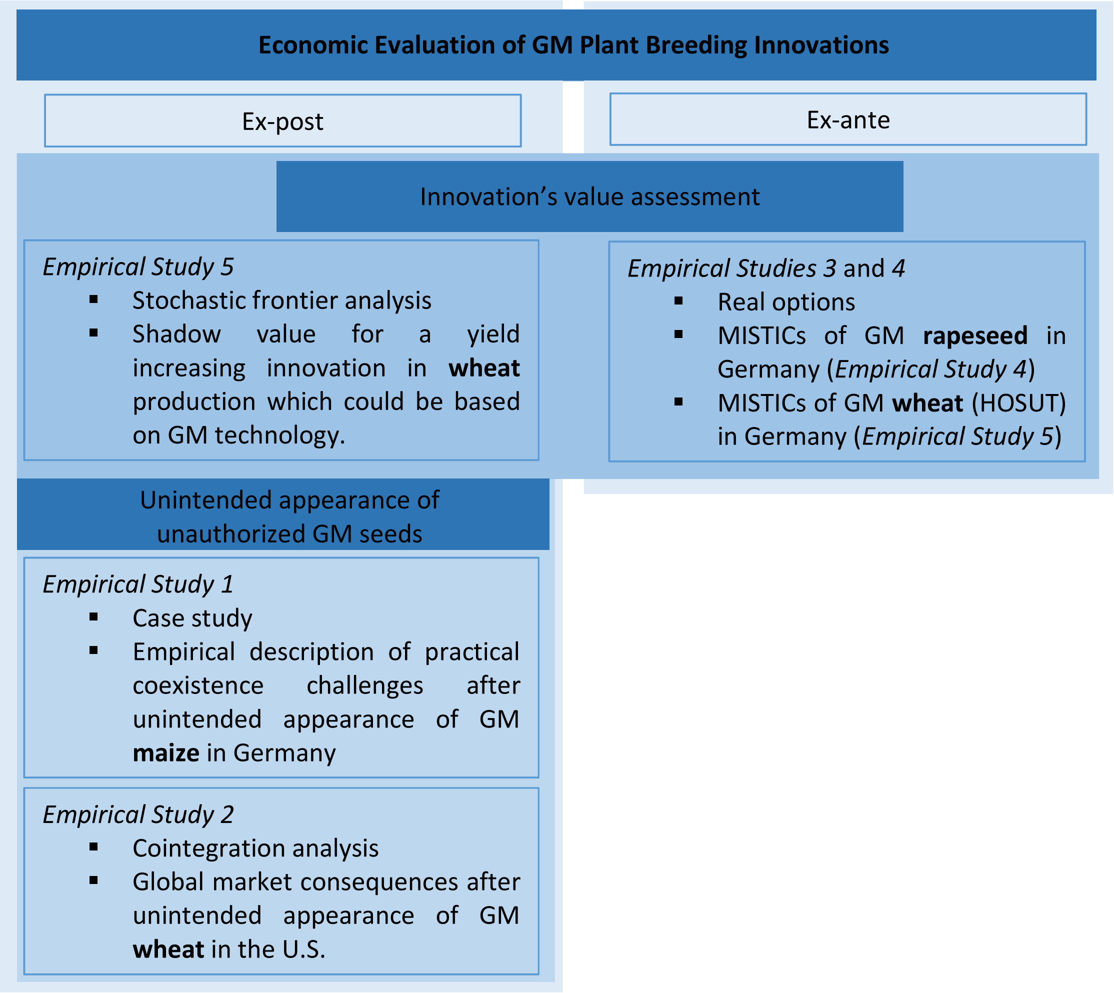
SS' represents the isoquant of fully efficient farms. As Q and Q' are part of the isoquant, the farms represented by these points will have a DF value of 1. Thus, they would be considered as technically efficient. A farm which uses the input combination represented by P is considered technically inefficient. The distance QP indicates the technical inefficiency of the farm producing with the input combination P and the amount by which all inputs could (proportionally) be reduced under efficient production without a reduction in output. The TE of a farm can be measured by the ratio TE= OQ/OP, which takes values between 1 and 0. A value of 1 implies (full) technical efficiency of the farm. If price information is given an input-output distribution can also be assessed concerning its allocative efficiency. In *Figure 6*, the input price ratio is represented by the slope of the isocost line; AA'. The resulting allocatively efficient point is Q'. The distance between R and Q, which is on the same isocost line as Q', represents the possible reduction in production costs if inputs would be allocatively and technically efficient.

The presented concept of one output and two inputs can be extended to multi inputs and outputs. Further, an estimated DF contains more than just efficiency information about a productions process. For example, in the *Empirical Study 5* the characteristics of DFs are used to derive marginal shadow values.

Linkages between the empirical studies

The empirical studies in this dissertation can be distinguished in an ex-post and an ex-ante analytical perspective. *Figure 7* indicates their linkages and differentiations of the empirical studies.

Figure 7: Linkages between the empirical studies



Note: MISTICs: maximum incremental social irreversible costs

Source: Authors' own compilation

The *Empirical Studies 1, 2,* and *5* take an ex-post perspective. In the *Empirical Studies 1* and *2*, the research aims on the challenges and consequences of past events (unintended appearance unauthorized GM seeds) and in the *Empirical Study 5* observation of past production data are used to determine marginal shadow values (MSVs). The *Empirical Studies 3, 4,* and *5* have the similar aim to assess the value of an innovation in crop production. However, their approaches are different. In the *Empirical Studies 3* and *4*, the innovation’s value is determined by future incremental benefits—ex-ante—with past observations of prices, yields, production costs, and adoption patterns. Further, private (farm) and non-private (society or environment) benefits are considered and eventually the MISTICs are determined. In the *Empirical Study 5*, the innovation’s value within current production systems is determined based on detailed farm level data (future private as well as environmental benefits are not considered). Both approaches are justified and appropriate with respect to the different research questions.

Empirical Study 1

Consequences of Adventitious Presence of Non-approved GMOS in Seeds: The Case of Maize Seeds in Germany

The content of this empirical study was published as a book chapter:

Wree, P., & Wesseler, J. (2016). Consequences of Adventitious Presence of Non-approved GMOS in Seeds: The Case of Maize Seeds in Germany. In *The Coexistence of Genetically Modified, Organic and Conventional Foods* (pp. 177-183). Springer New York.

Introduction: Adventitious presence of GMOs in German fields

In Germany, seeds have a zero tolerance for traces of GMOs which are not approved for cultivation in the EU (BUNDESVERWALTUNGSGERICHT, 2012). However, adventitious presence of unapproved events in seeds may happen. That can be the cause for unintended release of GMOs into the environment. Two of these cases have been broadly discussed in the media. In 2010 the BASF GMO potato variety Amadea appeared in fields of the BASF GMO potato variety Amflora in Sweden. In contrast to Amflora, Amadea was and is not an approved variety for commercial cultivation in the EU. In another case, seed samples of the maize variety PR38H20 from Pioneer, dedicated for the German market, were tested positive for the Monsanto GMO event NK603. Varieties including this event are not approved for cultivation by the EU. But by the time positive test results have been announced, relevant maize seeds were sold to farmers and sown. Problems that appeared during the practical handling of that issue revealed that there is a lack of legal guidelines and regulations for the situation of unintended release of unapproved GMO varieties in the EU. In the following case study, we will focus on the PR38H20 case.

History of the adventitious presence of GMOs – the Amflora and the PR28H20 case

In 2010 the BASF GMO potato variety Amadea was found in fields of the BASF GMO potato variety Amflora in Sweden. The harvest of the fields was assigned as commercial plant material for the Amflora potato. However, while, Amflora was an approved variety for commercial cultivation in the EU, Amadea was only authorized to be cultivated for research. In the case of the unintended presence of the Amadea potato in Amflora fields, it is important to mention that those fields were not cultivated by usual farmers for the consumer market. The harvest was assigned as plant propagation material for the Amflora potato. BASF documented that of the 680 000 potato plants on Amflora fields, 47 were identified as Amadea potatoes. Even though the rate of admixture was under 0.01%, the entire harvest was destroyed (BASF PLANT SCIENCE, 2010).

Also in 2010 229 German farmers in the federal states of Lower Saxony, Bavaria, Baden-Wuerttemberg, Brandenburg, Rhineland-Palatinate, Mecklenburg-Hither Pomerania and Hesse were requested to destroy their maize fields with a total area of 1650 hectares, on which they probably cultivated GMOs unintentionally (AGRARHEUTE, 2010). The detailed development of this case was as follows:

In February 2010 the Lower Saxony State Office for Consumer Protection and Food Safety found traces of GMOs in various seed lots of Pioneer's maize variety PR38H20 that they analyzed. By the middle of March 2010, the Ministry of Agricultural for Lower Saxony should have been informed about suspicious test results showing traces of GMOs in maize seed samples of PR38H20. In such a situation, the Agricultural Ministry usually informs the seed company immediately and the seed company has time to withdraw the suspicious or positive tested seeds from the market prior to their sale to farmers. However, the Ministry of Agricultural for Lower Saxony only informed other federal agricultural ministries and Pioneer at the end of April 2010 (BIOLAND, 2010). Simultaneously, the ministry asked Pioneer for detailed information about their supply chain for the relevant seeds. At first Pioneer refused to supply this information. Only after a verdict from the Administrative Court of Lower Saxony dated the 4th of June 2010 did Pioneer disclose the names of the relevant seed traders (BIOLAND, 2010). By that point in time farmers had already sown their maize crops. In the beginning of June 2010, the respective federal agricultural ministries contacted the relevant seed traders and gathered information about the farmers that bought PR38H20 maize seed with the identification numbers D/H4629/556W and D/H4629/831W. Only those lot numbers tested positive for traces of NK603. By the middle of June, the farmers who planted the specific PR38H20 seeds received a letter from their federal agricultural ministries with the decree to destroy their maize plants probably planted with adventitious presence of NK603. The decree didn't include any guarantee of financial compensation. At that time of the year it would have been very difficult to replant a new crop and obtain an adequate yield. The farmer's union—Deutscher Bauernverband (DBV)—stepped in and advised the farmers to file a case against the state's decree (TOPAGRAR, 2010b) and simultaneously announced that they would file a case against the federal state of Lower Saxony and Pioneer. Meanwhile, as requested, the farmers destroyed their crops and documented their steps.

Thereafter there was recrimination between the federal state of Lower Saxony and Pioneer. Eventually, after negotiations with the federal state of Lower Saxony and the DBV, Pioneer offered an immediate compensation payment of € 1800 per hectare to the affected farmers. By November 2010, Pioneer announced that 228 out of 229 affected farmers had accepted their offer (AGRARHEUTE, 2010).

Critical Assessment of the PR38H20 case

By the time only Monsanto's GM maize MON 810 was approved for cultivation in the EU. Nevertheless, in Germany the cultivation of the approved GMO variety MON 810 was only authorized from 2005 to 2008. The cultivation of the Amflora potato was permitted in 2010. However, since 2012 no planting of Amflora potatoes has taken place in the EU (BASF PLANT SCIENCE, 2013).

What distinguishes the BASF Amflora and the Pioneer PR38H20 cases is that farmer's compensation was not an issue in the case of Amflora. Situations similar to the BASF Amflora case, in which seeds are tested positive for adventitious presence of non-approved GMOs and therefore are rejected for the European seed market, occur regularly. In general, in Europe seed lots with an identification number entering the market are tested for adventitious presence of unapproved events. In 2013 for example, 498 maize seed lots were tested in Germany, and 10 of them were not approved because they contained traces of GMOs (TOPAGRAR, 2013). As yet, there are no EU regulations about a threshold level for GMOs in conventional seed material. That means there is a de facto zero tolerance for traces of GMOs in conventional seed material—an interpretation confirmed for Germany in February 2012 by the Federal Administrative Court (BUNDESVERWALTUNGSGERICHT, 2012).

Seed companies and breeder associations such as the Bundesverband Deutscher Pflanzenzüchter (BDP) have demanded the implementation of a more practical threshold (TOPAGRAR, 2013) as, for example, maize seeds are often produced in countries such as Chile or Argentina where a number of events are cultivated that have no approval for cultivation in the EU. Adventitious presence of GMOs in seeds due to cross-pollination is difficult to avoid in those areas. Before seeds are sold to farmers, seed samples are taken annually by the federal states of Germany to test for traces of GMOs. As mentioned earlier, in 2013, 498 such samples were taken for maize seeds. By contrast, around

252,000 different identification numbers for lots of maize seed are sold annually. The samples are often deliberately taken from seed lots originating in countries like Chile or Argentina, since the chance for adventitious presence of GMO is more likely.

Usually a seed company will be informed when a federal institution takes a sample from its seeds; thereby the seed company also has an opportunity to take a sample from the same seed lot.

After the federal institution takes the sample, it usually takes about two weeks before the seed company is informed of the test results. Seed companies often halt the sale of their seeds with the relevant identification number for this time period or until they receive the information of no presence of unapproved events from the federal institution. Seed companies are not obligated to halt sales, and obviously that did not happen in the PR38H20 case. The tests are done by a standardized polymerase chain reaction (PCR) method. Considering that samples are tested for very low concentrations, these being at the limit of detection, breeders and seed companies have another reason to demand a reasonable threshold level (SAUTER, 2013).

In February 2010, the tests results of the seed samples for the maize variety PR38H20 from Pioneer with the identification numbers D/H4629/556W and D/H4629/831W indicated GMO contaminated seed material (TOPAGRAR, 2010b). Commingling or cross-pollination were possible causes as the amount present was quite low. The tests done by the Lower Saxony State Office for Consumer Protection and Food Safety only showed “conspicuous” signs for GMO presence in the seed sample. For an actual proof of GMO-contaminated seeds the concentration (under 0.1%) was too low (TOPAGRAR, 2010d). Nevertheless, with such a test result seeds would not be approved and would not enter the market.

As mentioned before, seed material testing positive for traces of GMO is not unusual but what happened in the Pioneer PR38H20 case was that the identification numbers involved were not withdrawn from the market but instead delivered to the retailers and planted by the farmers. In particular, this fact reveals the weaknesses of the current protective system against GMO-cultivation in Europe. It shows the practical problems and legal uncertainties market participants face when GMOs are unintentionally present in seeds.

The farmers were the group of market participants who suffered as they have to trust the seed companies and the federal institutions who guarantee the quality of the seed material they purchase. When the relevant farmers were requested in writing by their federal agricultural ministry to destroy their crops planted with PR38H20 maize with the identification number D/H4629/556W and D/H4629/831W, their compensation for correcting a third party’s mistake was not mentioned. Within the decree of destruction the federal states justified the action by referring to the genetic engineering law, stating that genetically modified material which is not approved as harmless should not be released into the environment (TOPAGRAR, 2010b). However, this law does not regulate the reimbursement of farmers for cases like this. According to the German government, the genetic engineering liability law (Gentechnikhaftungsrecht) only regulates the handling of approved GMOs. For liability claims in context with non-approved GMOs, the regular civil law applies.

Further, farmers faced practical difficulties when they were requested to destroy their maize. The later the request came during the growing period the more difficult it became for the farmers to destroy their maize plants. Simple tillage was often insufficient to completely eradicate the crop. Thus, the farmers often had to perform multiple treatment procedures. Some farmers planted a new maize crop immediately after a first tillage. Those farmers often experienced problems as some plants survived the initial tillage treatment intended to eliminate them. In these cases hand weeding of the surviving old maize plants was often the only possible solution left. Even if the farmer destroyed the crop immediately after the state issued its request, it was more than one month after the recommended planting date for a new maize crop. An alternative was to plant a cover crop such as clover. However, the climatic conditions (heat and drought) at that time of the year are not ideal for establishing a new crop. Additionally, some farmers had contracts for the delivery of their maize to biogas plants and anticipated penalties if they were unable to fulfill their commitments (TOPAGRAR, 2010b).

Farmers claimed compensation payments for their extra work as they could not be held responsible for the adventitious presence. Neither Pioneer nor the federal states contradicted the claim at any point in time. But since there are no regulations for such an event, it was unclear who was responsible. The federal state of Lower Saxony did not acknowledged any mistakes in the handling of the case; instead it blamed Pioneer for placing the seeds on the market before they had knowledge about the test result. Furthermore, the federal state of Lower Saxony complained that Pioneer did not give voluntary information about their supply chain (TOPAGRAR, 2010a). Conversely, Pioneer never claimed responsibility, but argued that the Lower Saxony Ministry of Agricultural knew about the suspicious test results for more than 10 weeks before they were informed on the 26th of April 2010 (TOPAGRAR, 2010d).

Pioneer was under considerable pressure to assist the affected farmers. Pioneer decided to offer immediate financial support or compensation payments without admitting guilt. They planned on getting reimbursed for such a payment after suing the Federal State of Lower Saxony (PIONEER DU PONT, 2010). When Pioneer negotiated with the DBV about the compensation payments their initial intention was to pay under certain conditions only. Pioneer's liability to the farmers should be clarified in a test case against a farmer. Therefore, at least one farmer should sue Pioneer to bring about a test case. If the farmer would lose the lawsuit, there would have been the option for the farmers to pay the compensation payment back to Pioneer. Pioneer argued that a voluntary payment to the farmers will lower Pioneer's chances of getting reimbursed in the event of the later suing the federal state of Lower Saxony (TOPAGRAR, 2010c). The condition of the test case was not included in the final offer Pioneer made to the farmers (TOPAGRAR, 2010b).

After several meetings and negotiations with the federal State of Lower Saxony, the DBV, and farmers, Pioneer agreed on paying a compensation of € 1800 per hectare to the affected farmer. 228 farmers (out of 229 affected farmers) accepted the offer. In total Pioneer paid € 2,970,000 for 1650 hectares (AGRARHEUTE, 2010).

By the end of 2010, Pioneer announced that there would be three objectives for law suits. Measures are currently underway for achieving these objectives (see also *Table 3*).

- First, there is a test case at the Bavarian civil court in which a Bavarian farmer sued Pioneer for supplying seeds with adventitious presence of a GMO. Pioneer welcomes the accusation since the law case should clarify liabilities for future similar cases. In the initial trial, Pioneer was not held responsible. The case is currently under appeal.
- Second, Pioneer sued the federal state of Lower Saxony at the Lower Saxony administrative court for neglecting their communication duty after testing samples of PR38H20 positive for adventitious presence of GMOs.
- Third, two affected farmers (one from Bavaria and on from Lower Saxony) sued the federal states of Lower Saxony and Bavaria, respectively, for the decree to destroy an established maize crop. In both cases Pioneer gave legal support to the farmers in the trails at the respective administrative courts. The case against the federal state of Bavaria is currently under appeal after the farmer sued the federal state of Bavaria on his own and the case was dismissed (TOPAGRAR, 2010b).

Table 3: Details of Court Cases

Subject of the law case	**Parties involved**	**Aim**
Supply of seeds with adventitious presence of GMO	Bavarian farmer sues Pioneer	Clarification of liabilities
Liability claim for neglect communication duty	Pioneer sues the federal state of Lower Saxony	Reimbursement of Pioneer for the financial support paid to the farmers
Administrative court process about the decree to destroy an established maize crop	A Bavarian farmer, supported by Pioneer, sues the federal state of Bavaria A Lower Saxon farmer, supported by Pioneer, sues the federal state of Lower Saxony	Support of the farmers and clarification of liabilities

Note: Table confirmed by Pioneer

Source: Authors' own compilation

Lessons learned:

- Adventitious presence of unapproved GMO events in seeds can result in legal insecurity. Especially, since there is a zero tolerance for GMOs in conventional seeds.
- As long as legal standards have not been implemented that assign responsibilities and regulate liabilities in cases of infringement, adventitious presence of GMOs in conventional seeds can result in extra costs for all parties involved.
- Communication between the different players (state, seed companies, farmers association and farmers) plays an important role in reducing costs due to adventitious presence in seeds.
- Currently, from a legal perspective, farmers who unintentionally and unknowingly sow the "wrong" seeds have to bear extra costs at least initially. A legal framework for reimbursement in such a case is not in place yet.

Empirical Study 2
The Impact of GMO Appearance on the global wheat market

The content of this empirical study was published as a conference article:

Wree, P. and H. Gerhard (2015). The impact pf GMO appearance on the global wheat market. In, *54th Annual Conference, Göttingen, Germany, September 17-19, 2014*. German Association of Agricultural Economists (GEWISOLA).

Appendix 1 includes a poster about the study's content

Abstract

During June and July 2013 Japan and the Republic of Korea banned imports of U.S. wheat after traces of a GMO have been found in wheat samples from Oregon. We employ periodic cointegration analysis for different regional wheat futures and Portland spot prices to investigate if price formation on global wheat markets changed fundamentally during the time of the ban. Results show that the relationships between most of the price pairs changed significantly. In our view, the changed price formation illustrates the effect of unintended release of the GMOs within GMO reluctant trading restrictions.

Keywords: Wheat markets, GMO wheat, price linkages, nearby futures, cointegration

JEL classification: Q13, Q17, Q18

Introduction

On 05.05.2013 the Oregon State University informed the United States Department of Agriculture (USDA) that wheat samples from Oregon were tested positive for glyphosate resistance introduced by genetically modification (GM) technology. A farmer sent the plant samples to the Oregon State University as they had been unaffected by his glyphosate treatment. On 29.05.2013 the USDA confirmed the testing results (USDA, 2013a). Thereafter the Japanese government immediately halted wheat imports of Soft White Wheat (SWW) and Wheat White (WW), which are produced in the Oregon area and to a large extent exported to Asia (TAKADA, 2013). Two days later, the Republic of Korea also stopped part of their U.S wheat imports and the EU advised their member states to intensify testing for traces of genetically modification organisms (GMOs) in U.S. wheat imports (SHANNON, 2013). After one month, the Republic of Korea returned to import SWW and WW. However, the Korea Flour Mills Industrial Association cautioned, that for the future all U.S. white wheat consignments should be inspected and approved by the Korea Food & Drug Administration before reaching consumers (KWANWOO, 2013). Japan restarted their imports after a two months break (ASSOCIATED_PRESS, 2013).

The responsible state organs were unable to present a cause for the occurrence of the GM wheat. Thus, the problem remains unsolved and possible negative consequences for following production years cannot be excluded.

Wheat is the only major crops in the U.S. without any GM products on the market. However, Monsanto has already developed a glyphosate resistant GM breed called MON 71800, which was approved by the FDA for use in food production (FDA, 2004). But Monsanto stated under pressure from the U.S. Wheat Associates that it would only introduce MON 71800 in Canada and the U.S. simultaneously. Canada refused the approval of MON 71800 and therefore it has never been commercialized (BERWALD, 2006). Especially the strict import regulations for GM wheat in many foreign countries such as Japan and the Republic of Korea speaks against an introduction in the U.S.—the world's largest wheat exporter (USDA, 2013c). The U.S. accounted for around 20 percent of the world's wheat exports in 2012/2013 (USDA, 2013b). Japan and the Republic of Korea are the sixth and eighth largest wheat importer in the world, respectively (USDA, 2014c). In 2012/2013 53.8 percent of Japan's and 24.1 percent of Korean's wheat imports came from the U.S. (USDA, 2014c).

To analyze the impact of the temporary import ban we applied periodic cointegration analysis with the Portland spot price and nearby futures prices from America, Europe and Australia. Our results give evidence for a distortion of global wheat price relationships after the implementation of the ban.

Cointegration analysis was used in different studies to study market relationships in the agricultural sector. BAEK and KOO (2006) and MOHANTY and LANGLEY (2003) found cointegration relationships between the grain markets in the U.S. and Canada. GHOSHRAY and LLOYD (2003) compared eleven wheat varieties with different end use and geographic origins, including North and South America, Australia and Europe wheat price. Their results also suggest a general highly integrated wheat market. GOYCHUK and MEYERS (2011) used monthly wheat prices for the Russian Soft Wheat and Ukrainian Feed Wheat (Black Sea ports), Canadian Western Red Spring Wheat (St. Lawrence), U.S. Soft Red Winter Wheat (Gulf ports), and French Soft Wheat (Rouen) from July 2004 till October 2010. They found that Black Sea soft wheat prices are cointegrated with EU (French) wheat prices, but not with those of the U.S. and Canada.

Some studies include structural breaks into their cointegration analysis. Results by GHOSHRAY (2007) suggest general cointegration between the U.S. and Canadian durum wheat prices with a structural break in September 1995 when the WGTA was repealed. BARASSI and GHOSHRAY (2007) analyzed the long term relationship between U.S. and EU wheat export prices over the period 1981–2000. They found that only after the EU's common agricultural policy (CAP) reforms in 1992 cointegrated price relationships established.

Our cointegration analysis with international price data from different regions of the world is based on the Law of One Price (LOP) theory. LOP means that price will stay in a long term equilibrium relationship due to arbitrage and substitution. We will give evidence for LOP and show changes in the relationships before, during and after a specific, temporary and political implemented trading restriction.

The rest of the paper is structured as follows. Section 2 introduces the used data. Section 3 discusses the empirical method of cointegration. Section 4 presents the empirical results and section 5 draws a conclusion and summarizes the findings of the paper.

Data

For the analysis, we consider the daily spot price for SWW from Portland and daily nearby futures[11] prices from five wheat futures. Portland is the most important export location for wheat from the U.S. to Asia. Therefore, its spot price for SWW reflects the price of the good, which was most directly affected by the ban. Daily price information are provided by the USDA (USDA, 2014a). Three futures are traded in America at the CBOT[12], KCBT[13], and MGEX[14], one futures contract is traded in Europe at the MATIF (Euronext) and another in Australia at the ASX. The nearby futures price information are obtained from HGCA (2013).

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[11] The nearby contract is the contract with the earliest date for delivery, i.e. the earliest settlement date. Markets most often trade several contract months simultaneously for each commodity.

[12] Underlying wheat subclass: Soft Red Winter wheat (SRWW)

[13] Underlying wheat variety: Hard Red Winter wheat HRWW

[14] Underlying wheat variety: Hard Red Spring wheat (HRSW)

We used nearby futures prices for the sake of their transparency. However, most of the futures are characterized by a different underlying wheat class (i.e. CBOT, KCBT and MGEX) and none of the futures is specific for SWW and WW. In order to compare futures and spot prices, we assume constant basis over time and a similar reactions to new market information and external price shocks (LAI and LAI, 1991: 567).

The time range we consider runs from 01.08.2006 until 17.01.2014. All prices, as presented in *Table 4*, are converted into Euro per metric ton using daily specific currency rates obtained from HGCA (2013). When there were no price information data available for a single day (because of a national holiday) the missing price was estimated as the price from the previous day. The only exceptions are the first four trading days after the ban (from 30.05.2013 until 04.06.2013). Since there were no available spot prices for Portland we left a gap for this period. Furthermore, all wheat price time series (WPTSs) are transformed to natural logarithmic form.

Table 4: Descriptive price data in €/ton from 01.08.2006 until 17.01.2014

(Obs: 1930)	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Portland	186.21	49.47	106.59	396.23
MATIF	192.70	46.74	115.75	292.75
CBOT	177.06	38.17	103.17	312.63
KCBT	188.04	40.28	114.33	326.55
MGEX	205.05	54.94	119.05	595.16
ASX	194.89	45.22	118.78	333.11

Source: Authors' own compilation

Empirical method

We apply periodic cointegration analysis to determine the relationship between different WPTS in different points in time. Following ENGLE and GRANGER (1987) non-stationary time series are cointegrated if a linear stationary combination of the time series exists. For the cointegration analysis in different groups and over different time ranges we perform the Johansen test for cointegration (JOHANSEN, 1988). This multivariate cointegration approach is able to analyze the co-integration relationship between more than two variables in one simultaneous system using a dynamic vector auto regressive (VAR) model. Within a group all time series, less than all or no time series can be cointegrated. If times series within a group are cointegrated, it implies that these time series have the same stochastic trend (MASIH and MASIH, 1996).

For a detailed inside of global wheat price relationships the WPTSs are analyzed pairwise and in three different groups over four different time ranges. The first group obtains all WPTSs and is therefore named ‘All’. The second group, named ‘Portl./U.S.’, represents all U.S. wheat futures (CBOT, KCBT, MGEX) and Portland’s spot prices. The third group obtains the futures, which are located outside the U.S. (MATIF, ASX) and Portland’s spot prices and is named ‘Portl./non-U.S.’. The groups and the pairwise cointegration are analyzed in four different time ranges (*Table 5*).

Table 5: Time ranges for cointegration tests

Time range	**from**	**to**	**Number of observations**
A	01.08.2006	17.01.2014	1925
B	03.04.2013	29.05.2013	41
C	05.06.2013	31.07.2013	41
D	01.08.2013	26.09.2013	41

Source: Authors’ own compilation

Since we had 41 daily price observations during the ban, we adjusted the time ranges B and D to facilitate similar time span comparisons. We chose the time ranges because we assume a structural break in the wheat market price relationships with the introduction of the ban by Japan (30.05.2013) and its lifting (31.07.2013).

Prior to performing the Johansen test it is necessary to check the level for which the time series are stationary. This is conducted by performing the Augmented-Dickey-Fuller (ADF), Philips Perron (PP) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests. ADF-test and PP-test share the same null hypothesis, but the PP-test adds an automatic correction to the ADF-test, which allows auto-correlated residuals (GOYCHUK and MEYERS, 2011). Different to ADF and PP the KPSS-test assumes the time series to be stationary at the null hypothesis.

If the WPTSs full fill the condition of non-stationarity in I(0) and stationarity in I(1) we can continue and perform the Johansen test. First, the optimal number of lags for the Johansen test must be found. Lag selection was based on minimizing the Akaike criteria examining the WPTSs (RAMOS, 2000). We choose the maximum number of lags for which we can reject the 5% critical value of the Akaike, and by that imply stationarity. Because the Johansen-test is performed for all WPTSs together and for other WPTSs combinations we run this test one time for each combination of time series.

The Johansen-test for cointegration is based on a VAR standard form (JOHANSEN, 1988, JOHANSEN, 1991, JOHANSEN, 1998)

The VAR can be formulated as;

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \cdots + \Gamma_{k-1} \Delta X_{t-k+1} \Pi X_{t-k} + \varepsilon_t \qquad (9)$$

where X_t is an $n \times 1$ vector of endogenous variables (i.e. WPTS), Δ denotes the first difference, Γ captures the dynamic effects and Π contains the long run effects of the considered time series, k is the lag length and ε_t are independently and identically distributed white noise error terms (BAEK and KOO, 2006). The number of cointegration vectors is determined by the rank of Π. When the rank of Π is reduced $(r < n)$ then there exist r linear combinations of the n variables in X_t that are I(0) (GHOSHRAY and LLOYD, 2003). For a group of n prices, the existence of $n-1$ cointegration vectors implies complete cointegration of the time series of this group (GOODWIN, 1992). Complete market integration implies that any single price should be representative of the entire group of prices.

The Johansen procedure requires testing the cointegration rank r by sequences of hypothesis tests. If the hypothesis of $r \leq n-1$ (with $n \geq 1$) can be rejected and $r \leq n$ cannot then the time series are cointegrated with at least n common stochastic trends. If the trace statistic of the Johansen test at $r = 1$ exceeds its critical value, one rejects the null hypothesis that there is one or fewer cointegration relationships. If the null hypothesis cannot be rejected at $r = 2$ we conclude two cointegration relationships within our set of variables. In the case of two time series if $r = 0$ can be rejected and $r \leq 1$ cannot, then time series are cointegrated and exhibit a long-term equilibrium relationship (LEHECKA, 2013).

Complete market integration implies that any single price should be representative of the entire group of prices, or alternatively, only a single stochastic trend should exist among the prices. Thus for a group of n prices, there should be $n-1$ cointegrating vectors to imply complete market integration (Goodwin 1992).

Empirical results

We conducte cointegration analysis on wheat futures prices and the spot prices from Portland to examine a possible impact of the import ban. Therefore, we determine four different time ranges for a detailed cointegration analysis. Including three shorter time ranges (41 observation) pre, during and after the ban and one long term time range (1925 observation), which also includes the shorter time ranges.

Test for stationarity

As mentioned earlier, it is necessary to test for stationarity before continuing with the cointegration testing procedure. All test for stationarity are implemented for level and first difference of each WPTS and the different time ranges. *Table 6* shows the results of the ADF for the time range A and D, KPSS test for time range B and PP test for time range C. For each WPTS the ADF in time range A and D as well as the PP in time range C fails to reject the null hypothesis of non-stationarity at I(0) (Levels) and reject the same null hypothesis at I(1) (first difference) at a 5 percent significance level. The KPSS in time range B rejects the null hypothesis of stationarity at I(0) and fails to reject the same null hypothesis at I(1) at a 5 or 10 percent significance level.

All three tests have also been performed for the time ranges A, B, C and D. For each time range at least one of the tests indicated stationarity in I(1) as exemplarily shown in *Table 6* with a significance level of 5 percent or 10 percent.

Table 6: Test for stationarity; ADF for time range A & D, KPSS for time range B, PP for time range C

Test for stationarity **Time range: A, B, C, D**								
With constant and trend								
	Time range: A		Time range: B		Time range: C		Time range: D	
	ADF		KPSS		PP		ADF	
	Levels	First difference	Levels	First difference	Levels	First difference	Levels	First difference
ASX	-2.431	-34.048**	0.119*	0.082	-2.471	-16.641**	-2.593	-5.963**
CBOT	-2.637	-16.914**	0.048**	0.074	-2.436	-4.057**	-1.357	-9.841**
KCBT	-2.175	-44.755**	0.148**	0.037	-2.463	-4.076**	-2.619	-7.569**
MATIF	-1.875	-16.524**	0.148**	0.094	-2.828	-5.724**	-2.843	-7.573**
MGEX	-1.855	-16.751**	0.159**	0.108	-2.354	-5.298**	-3.247	-3.497**
Portl.	-2.495	-9.8017**	0.198**	0.062	-2.327	-4.595**	-1.234	-8.291**

Note: The optimal lags for the ADF (Augmented Dickey-Fuller) test were selected based on optimizing Akaike's Information Criteria (AIC), using a range of lags. The bandwith for PP (Phillis-Perron) and KPSS (Kwiatkowski-Phillips-Schmidt-Shin) are selected using the Newey-West method.
*** and * denote rejection of the null hypothesis of unit roots/ non-stationarity for ADF and PP at the 5 percent and 10 percent significance levels, respectively.*
*** and * denote rejection of the null hypothesis of no unit roots/ stationarity for KPPS at the 5 percent and 10 percent significance levels, respectively.*
For ADF and PP the critical values at the 5 percent and 10 percent significance levels are -3.4121 and -3.1280, respectively. The critical values are based on McKinnon (1996)
For KPSS the critical values at the 5 percent and 10 percent significance levels are 0.146 and 0.119, respectively.
The critical values are based on Kwiatkowski-Phillips-Schmidt-Shinn (1992)
All tests are performed assuming the data have an intercept and a trend.

Source: Authors' own compilation

We assume the results to be sufficient in order to assume that all tested time series are stationary in their first difference (I(I)). That provides the possibility of cointegration relationships.

Johansen Cointegration

We perform the cointegration test in groups and pairwise over the time ranges A, B, C, and D. It is important to consider that usually cointegration test of shorter time periods have less power (QUINTOS, 1995). Therefore, we compare the period of the the ban (time range C) with time range before (B) and after the ban (D) of the same length (41 observation).

Cointegration tests in groups

Following LEHECKA (2013) we test if the rank of Π or the number of cointegration relationships remains stable over time. For each group tested the assumption is that if the number of cointegration relationships remains stable over time, the import ban had no impact on the wheat price relations.

First we determine the cointegration relationships for all WPTSs for the group 'All' (*Table 7*).

Table 7: Test for rank of cointegration matrix; Group: All; Time range: A, B, C, D

COIN All Time range : A, B, C, D				
	Trace statistics			
Hypothesized No. of CE(s)	Time range: A	Time range: B	Time range: C	Time range: D
Lag selection	4	4	4	4
$r = 0$	157.4650 *	215.0436 *	211.9355*	255.11*
$r \leq 1$	107.1498*	141.7259*	118.9490*	132.94*
$r \leq 2$	65.8103*	74.9068*	71.8112*	70.8537*
$r \leq 3$	38.8637*	28.2936	28.8657	36.070*
$r \leq 4$	18.8503	8.6504	9.7388	12.201
$r \leq 5$	5.7571	0.0123	0.5259	1.8927

** denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.*
The critical value (at the 5 percent significance levels) for $r = 0, \leq 1, r \leq 2 , r \leq 3 , r \leq 4$ and $r \leq 5$ are 103.847, 76.973, 54.079, 35. 193, 20.262 and 9.165, respectively. Critical values are based on MacKinnon-Haug-Michelis (1999).
Lags are selected by the Akaike criteria (VAR lag selection)

Source: Authors' own compilation

The tests show that there are less cointegration relationships in the shorter time ranges (B, C, D). However, over the shorter time ranges the number of cointegration relationships remains constant. That results indicates no disturbance on the global wheat market.

The next two group tests examine how the import ban may affected the U.S. (group 'Portl./ U.S.') and the non-U.S. (group 'Portl./ non-U.S.') wheat market. Both groups include Portland spot prices as a reference price as it reflects the price for (the banned) SWW. With the group 'Portl./ U.S.' we only consider the development of the U.S. wheat prices, including Portland's spot price and nearby futures from CBOT, KCBT, and MGEX (*Table 8*).

Table 8: Test for rank of cointegration matrix; Group: Portl./U.S.; Time range: A, B, C, D

COIN Portl./U.S. Time range : A, B, C, D				
	Trace statistics			
Hypothesized No. of CE(s)	Time range: A	Time range: B	Time range: C	Time range: D
Lag selection	4	1	4	2
$r = 0$	98.2356*	59.9626*	69.0589*	49.9571*
$r \leq 1$	59.4772*	34.6263*	21.7438	22.0082
$r \leq 2$	27.2147*	15.0015	7.1525	7.4307
$r \leq 3$	8.9150	2.7277	0.5909	2.2978
** denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels. The critical value (at the 5 percent significance levels) for* $r = 0, \leq 1$ *,* $r \leq 2$ *and* $r \leq 3$ *are 54.079, 35. 193, 20.262 and 9.165, respectively. Critical values are based on MacKinnon-Haug-Michelis (1999).* *Lags are selected by the Akaike criteria (VAR lag selection)*				

Source: Authors' own compilation

We can observe that in time range A all U.S. prices are cointegrated and thus have a common price movement independent of the variety or regional origin. The cointegration relationships decrease with shorter time period. Before the ban (time range B) the coinegration relationships are two and during the ban and after (time range C and D) one cointegration relationship remains.

With the group 'Portl./ non-U.S.' we consider the development of the European and Australian wheat prices combined with the price for SWW form Portland (*Table 9*).

Table 9: Test for rank of cointegration matrix; Group: Portl./ non-U.S.; Time range: A, B, C, D

COIN Portl./ non-U.S. Time range : A, B, C, D				
	Trace statistics			
Hypothesized No. of CE(s)	Time range: A	Time range: B	Time range: C	Time range: D
Lag selection	3	1	2	1
$r = 0$	51.0536*	32.793*	21.5839	33.9791*
$r \leq 1$	19.7313	13.7376	9.3763	11.2708

$r \leq 2$	4.7427	0.7778	3.6973	0.2216
** denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels. The critical value (at the 5 percent significance levels) for $r = 0$, $r \leq 1$ and $r \leq 2$ are 35. 193, 20.262 and 9.165, respectively. Critical values are based on MacKinnon-Haug-Michelis (1999). Lags are selected by the Akaike criteria (VAR lag selection)*				

Source: Authors' own compilation

For this group the rank of Π is one in the time ranges A, B, and D and during the ban (time range: C) even down to zero. This indicates that a possible negative price effect due to the ban of SWW was not transferred to the price of the other major wheat exporting areas of Europe and Australia.

Comparing the results of the cointegration analysis in the groups for Portl./ U.S. and Portland/ non-U.S. we can conclude that the cointegration relationships of Portland spot prices with other U.S. wheat prices is higher than Portland spot prices with wheat prices from Europe and Australia. Further, no cointegration relationship between Portland and non-U.S. wheat prices could be shown during the ban (time range C). The results suggest that a price effect on Portland wheat prices have rather been transmitted to U.S. than European or Australian wheat prices.

Pairwise cointegration tests

For a more detailed look at the development of the WPTSs we perform pairwise multivariate cointegration tests as done by GHOSHRAY and LLOYD (2003), GOYCHUK and MEYERS (2011), and LEHECKA (2013). Now the assumption is that if pairs remain cointegrated or not cointegrated over the time ranges, the import ban had no impact on the global wheat price relationships. The test for rank of pairwise cointegration matrix of time range A shows that 12 out of 15 WPTSs are cointegrated over the time range A (*Table 10*). The results support the finding of other studies that the wheat market is highly integrated even though wheat is a heterogeneous product with different subclasses (GHOSHRAY and LLOYD, 2003, GOODWIN, 1992, MOHANTY et al., 1998). The findings support the law of one price assumption within the global market for wheat (MOHANTY et al., 1998). With the test results in *Table 10*, we assume to determine the general pairwise cointegration relationship on the global wheat market.

Table 10: Test for rank of pairwise cointegration matrix; Time range A

COIN A	**Trace statistic**									
	CBOT		**KCBT**		**MATIF**		**MGEX**		**Portl.**	
ASX	$r = 0^*$	26.2484	$r = 0^*$	20.5363	$r = 0^*$	30.2839	$r = 0$	15.6700	$r = 0^*$	26.0597
	$r \leq 1$	6.5180	$r \leq 1$	4.8069	$r \leq 1$	4.6176	$r \leq 1$	4.2997	$r \leq 1$	4.8201
CBOT			$r = 0^*$	37.5718	$r = 0^*$	20.9531	$r = 0^*$	22.8171	$r = 0^*$	26.9687
			$r \leq 1$	8.1026	$r \leq 1$	4.1213	$r \leq 1$	5.5600	$r \leq 1$	4.7924
KCBT					$r = 0^*$	24.4446	$r = 0$	19.0547	$r = 0$	19.1823
					$r \leq 1$	5.1158	$r \leq 1$	4.3011	$r \leq 1$	4.9533

MATIF				$r = 0^*$ 20.4357 $r \leq 1$ 5.5197	$r = 0^*$ 21.5140 $r \leq 1$ 4.2116
MGEX					$r = 0^*$ 28.3673 $r \leq 1$ 6.3223

** denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.*
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999).
Lags are selected by the Akaike criteria (VAR lag selection)

Source: Authors' own compilation

Table 11 shows that the pairwise cointegration is already less for a shorter time range (41 observations) before the ban compared with the long run cointegration results. Still 10 out of 15 pairs are cointegrated. The CBOT futures are cointegrated with all other WPTSs. The results indicates the importance of the CBOT, as the most important agricultural commodity exchange, for global price determination for wheat.

Table 11: Test for rank of pairwise cointegration matrix; Time range B

COIN B	**Trace statistic**				
	CBOT	**KCBT**	**MATIF**	**MGEX**	**Portl.**
ASX	$r = 0^*$ 21.0159 $r \leq 1$ 7.1114	$r = 0^*$ 21.2994 $r \leq 1$ 3.8567	$r = 0$ 18.8520 $r \leq 1$ 1.8235	$r = 0^*$ 27.4522 $r \leq 1$ 3.4290	$r = 0^*$ 21.3217 $r \leq 1$ 8.9058
CBOT		$r = 0^*$ 21.9222 $r \leq 1$ 1.4391	$r = 0^*$ 22.1854 $r \leq 1$ 1.3300	$r = 0^*$ 23.4821 $r \leq 1$ 2.9545	$r = 0^*$ 30.6083 $r \leq 1$ 7.0045
KCBT			$r = 0$ 7.1108 $r \leq 1$ 1.3395	$r = 0$ 11.3797 $r \leq 1$ 3.0746	$r = 0^*$ 20.8883 $r \leq 1$ 3.6610
MATIF				$r = 0$ 9.5874 $r \leq 1$ 1.9352	$r = 0$ 19.6148 $r \leq 1$ 4.5290
MGEX					$r = 0^*$ 26.1467 $r \leq 1$ 8.6145

** denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.*
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999)
Lags are selected by the Akaike criteria (VAR lag selection)

Source: Authors' own compilation

The results in *Table 12* show that during the ban none of the pairs of the WPTSs had a cointegration relationships. Compared to 10 out of 15 cointegration relationships in time range B we can conclude a break in the general relation of global wheat prices in time range C.

Table 12: Test for rank of pairwise cointegration matrix; Time range C

COIN C	**Trace statistic**									
	CBOT		**KCBT**		**MATIF**		**MGEX**		**Portl.**	
ASX	$r = 0$	15.3158	$r = 0$	16.6678	$r = 0$	14.3118	$r = 0$	10.9577	$r = 0$	15.4034
	$r \leq 1$	5.7235	$r \leq 1$	7.1332	$r \leq 1$	4.8220	$r \leq 1$	3.2181	$r \leq 1$	4.9388
CBOT			$r = 0$	11.0566	$r = 0$	17.1504	$r = 0$	12.9727	$r = 0$	19.5560
			$r \leq 1$	1.0102	$r \leq 1$	5.0743	$r \leq 1$	2.5042	$r \leq 1$	7.4826
KCBT					$r = 0$	12.6453	$r = 0$	9.1155	$r = 0$	15.7990
					$r \leq 1$	3.1335	$r \leq 1$	0.9063	$r \leq 1$	6.6427
MATIF							$r = 0$	14.6961	$r = 0$	13.5362
							$r \leq 1$	2.6654	$r \leq 1$	5.5234
MGEX									$r = 0$	8.7772
									$r \leq 1$	2.6475

** denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.*
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999)
Lags are selected by the Akaike criteria (VAR lag selection)

Source: Authors' own compilation

In time range D only one cointegration relationship occurs (*Table 13*). That can be brought in the context of the ban in two different ways. Once the effect of the ban continuous after its lifting and prices continue to move different to their long term state. Second, when prices return to their general relationship after a break, the period in which that happen will not show cointegration relationships as well.

COIN D	**Trace statistic**									
	CBOT		**KCBT**		**MATIF**		**MGEX**		**Portl.**	
ASX	$r = 0$	18.0562	$r = 0$	14.0241	$r = 0$	16.5967	$r = 0$	12.7823	$r = 0$*	23.6616
	$r \leq 1$	3.3778	$r \leq 1$	2.2921	$r \leq 1$	3.7534	$r \leq 1$	3.3687	$r \leq 1$	4.2905
CBOT			$r = 0$	16.1831	$r = 0$	13.5609	$r = 0$	14.1559	$r = 0$	11.0597
			$r \leq 1$	6.9802	$r \leq 1$	5.3101	$r \leq 1$	2.4291	$r \leq 1$	0.8445
KCBT					$r = 0$	13.0421	$r = 0$	10.0209	$r = 0$	7.5965

			$r \leq 1$ 4.4936	$r \leq 1$ 2.8292	$r \leq 1$ 1.1769
MATIF				$r = 0$ 10.7173	$r = 0$ 8.6478
				$r \leq 1$ 2.9180	$r \leq 1$ 2.0507
MGEX					$r = 0$ 9.7724
					$r \leq 1$ 3.9338

** denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.*
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999)
Lags are selected by the Akaike criteria (VAR lag selection)

Table 13: Test for rank of pairwise cointegration matrix; Time range D

Source: Authors' own compilation

Conclusion

Our results show that in the long run (time range: A) most of the price pairs of the chosen WPTSs are cointegrated (12 out of 15), which supports the assumption of LOP even though wheat is due to its origin and physical characteristics a heterogeneous good. However, comparing different time periods and their cointegration relationship can give evidence for breaks and changes in the general market structure (BARASSI and GHOSHRAY, 2007, QUINTOS, 1995). We analyze the case of the import ban in 2013 by Japan and the Republic of Korea for U.S. wheat by comparing the cointegration relationships of WPTSs from America, Europe and Australia in time ranges before, during and after the ban (time ranges B, C, D) in groups and pairwise. Both test set-ups indicate less cointegration relationships during and after the ban compared with the time before the ban. The test in groups could not give sufficient evidence to support the hypothesis that the ban reduced cointegration relationships across WPTSs. However, the results of the pairwise cointegration analysis shows a clear change in cointegration relationships before and after the implementation of the import ban. The results indicate that the entire global wheat market experienced a break in its long term (time range A) price structures.

Conclusively, a relatively small ban, restricted to specific types of wheat (SWW and WW) and origin (Oregon), lead to general disturbance on the global wheat market. The reasons why not only price relationships with Portland spot prices have been affected are the social sensitive issue of GMO and that the cause for the contamination could not be clearly determined. Therefore, e.g. the European Commission urged member states to test all U.S. wheat shipments for traces of GMO. In case of positive findings the specific shipment would not be allowed for import. Thus, trading companies endured a more or less unknown risk of unintended contamination of their wheat exports from the U.S., which made U.S. wheat less attractive for trade.

Empirical Study 3

Genetically Modified Herbicide-Resistant Rapeseed in Germany: A Socio-Economic assessment

The content of this empirical study was published as a journal article:

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Abstract

The cultivation of transgenic rapeseeds is currently banned in Germany. Considering the reversibility, irreversibility and uncertainty in the context of costs and benefits of introducing herbicide-resistance rapeseeds (HR), we determine the maximum incremental social tolerable irreversible costs (MISTICs) of this technology for Germany. Results indicate that banning HR genetically modified rapeseeds is only appropriate if German society values the possible total accumulated irreversible costs (from its introduction until infinity) of this technology as at least € 1.105 billion or € 13.8 per citizen.

Keywords: Real options, rapeseeds, genetically modified organisms, irreversibility, social costs

JEL classification: Q12, Q15, Q16

Introduction

Many innovations in transgenic crops offer potential benefits to farmers but pose uncertain hazards to society. However, their adoption by farmers is only possible if the use of transgenic varieties is deregulated by society's institutions. This research aims to target the implicit regulatory challenge.

Many studies have shown that compared with their conventional counterparts, different transgenic crops offer advantages related to cost saving or yield increases (FINGER et al., 2011, KLÜMPER and QAIM, 2014, ZILBERMAN et al., 2010). On the other side, society's health-related and environmental concerns make transgenic crops a controversial topic, and some states reject this technology because of its potential long-term irreversible costs. Decision makers have to weigh these costs against the potential benefits to choose between the options of immediate releases or postponed decisions.

Rapeseed is used as animal feed, for human consumption, in industrial production, and—increasingly—as biofuel. Approximately 72.5 million tonnes of rapeseeds are grown annually (FAO, 2015); main producers are Europe, North America, China, India, and Australia. Europe is the world's principal rapeseed-producing region, with production amounting to 25.6 million tonnes in 2013. Within Europe, Germany, and France are the main rapeseed cultivators, accounting for approximately 40% of the total European production (FAO, 2015). However, genetically modified (GM) herbicide-resistance (HR) rapeseed varieties are cultivated only in Canada, the U.S., Australia, and Chile. Currently, approximately 25% of the global annual rapeseed production (on approximately 36 million hectares) is genetically modified; moreover, such production displays an upward trend (JAMES, 2014). In 2012 98% of the Canadian rapeseed production area (8.37 million hectares) was used for cultivating GM HR varieties (BROOKES and BARFOOT, 2014). Farmers in the European Union (EU) cannot experience possible benefits from cultivating GM HR rapeseeds, as currently none such variety is approved for cultivation. Nevertheless, six GM HR rapeseeds varieties a currently approved for food and feed and import and processing (gmo-compass.org, 2015). The main reason for a ban of GM crops cultivation, is that European decision makers evaluate possible irreversible costs of the technology as too significant compared with its potential benefits (ZILBERMAN et al., 2015). However, to our knowledge, so far no scientific study exists that credibly values either the possible irreversible costs or the possible benefits of HR rapeseeds for EU member states, their farmers and their citizens. To fill this gap with respect to scientific evidence, we conduct a socio-economic ex-ante assessment of GM HR rapeseeds in Germany in this study. The focus on only one European country is justified by the opt-out clause, which gives single member countries the option to decide whether or not to allow GM cultivation on their territory even though a GM variety is approved for cultivation on European level.

The introduction of Clearfield rapeseed variety in the German market in 2012—a conventional rapeseed variety with very similar agronomic characteristics as GM HR rapeseeds—highlighted that the irreversible hazards linked to agronomic disadvantages do not hinder the GM HR rapeseeds' approval process. This example demonstrates that the EU's opposition to approve GM crops is based on breeding technic characteristics and other political economy factors—to a lesser extent—the specific agronomic principle of operation.

We analyze the socio-economic potential of an immediate release of GM HR rapeseeds by considering private and social reversible and irreversible costs and benefits to determine the maximum incremental social tolerable irreversible costs (MISTICs) (DEMONT et al., 2004, WESSELER et al., 2007). MISTICs are based on the real options approach and can identify an upper bound—up to which the release or investment in a new technology can still be considered economically justified—for irreversible social costs. When a new technology is developed and submitted for cultivation approval, decision makers face the choice or option to authorising or banning its market introduction. A temporary ban is equal to postponing the decision and waiting for further information. The possibility of introduction implicates an option value, which is determined in this study as well. The decision criteria includes irreversibility and uncertainty of expected benefits and costs to society. The option should only be exercised if the benefits of an immediate release outweigh those of keeping the option and postponing the decision. MISTICs can be used to conduct a monetary evaluation of the situation as well as structure the decision finding process. The potential benefits of GM technology contrasted with society's health-related and environmental concerns and make transgenic crops based on GM a controversial topic. For modelling purposes, we formulate assumptions based on scientific studies examining the agronomic effects of GM HR rapeseeds and combine these findings with the rapeseed cultivation situation in Germany to calculate the possible benefits and costs for society. Furthermore, we aim to place an economic value on potential savings in carbon dioxide (CO_2) emissions to value the related positive environmental impacts.

Previous studies that socio-economically assess GM technology can be distinguished into those that take an ex-post or an ex-ante perspective. BROOKES and BARFOOT (2014) determine ex-post that since their introduction in 1999, GM HR rapeseeds had provided benefits worth US$ 268.8 million for U.S. agriculture15. FAGERSTRÖM et al. (2012) refer to a former study by Fagerstörm and Wibe which analyzed a possible economic gain of ca. € 10 million or ca. € 116 per hectare for Swedish farmers when farming HR rapeseeds. ZILBERMAN et al. (2010), FINGER et al. (2011), and KLÜMPER and QAIM (2014) provide analytical overviews of ex-post studies analysing the economic effect of GM crops such HR soybeans, maize and cotton, and HR soybeans for different regions. RAMASAMY et al. (2007), and STEIN et al. (2006) conducte economic ex-ante assessments of different GM crop innovations. Ex-ante studies using the theoretical concept of MISTICs have been conducted for HR sugar beets (DEMONT et al., 2004) and Bt and HR maize (WESSELER et al., 2007). In this study we determine

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[15] The annual rapeseed cultivation area in U.S. is 30–50% compared to Germany

MISTICS for GM HR rapeseeds in Germany and show how real options calculation can be used to economically evaluate the option of this innovation.

The paper proceeds as follows. The next section develops the theoretical concept of MISTICs based on a cost-benefits assessment structure. The following sections provide information on empirical data and followed by the presentation of the results as well as their discussion. The final section summarises our findings and offers conclusions.

Theoretical model and methods

In the approval process for innovations, decision-making bodies such as the European Commission should aim to maximise society's welfare (V), which can be described as;

$$maxV = (0, W + J - I) \qquad (10)$$

where W is the discounted total future incremental[16] net benefits and J and I are the discounted total future irreversible benefits and costs associated with the deregulation of the technology, respectively.

Net present value (NPV), as the standard neoclassical decision-making criterion, suggests to deregulate an innovative technology if the expected social reversible net benefits exceed the social reversible net costs. However, this approach considers neither uncertainty and irreversibility nor the possibility of postponing the decision. In our analysis, we use an ex-ante assessment model based on real options theory that explicitly considers these aspects. The theoretical basis for our analysis utilises the real options approach developed by DIXIT and PINDYCK (1994) and MCDONALD and SIEGEL (1986). In finance, this approach is considered an investment-decision-making tool, given its ability to incorporate the uncertainty of future revenues, irreversibility of investments, and possibility of postponing investment decisions. Our socio-economic assessment model can be regarded as an information or decision-making tool for politicians or decision-making bodies. The model's outputs are an option value, which gives a value to the possibility of introduction and a MISTIC value, which can be used as a decision criterion.

We apply our model to the situation in which a seed company applies for deregulation of GM HR rapeseeds in the EU. Similar to financial investment options, decision-making bodies can approve such an application immediately or postpone the decision and wait for further information. The real options approach for MISTICs is based on an American call option, which gives the holder the right—

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[16] As 'incremental', we consider the difference between the benefits or costs of GM crops and the benefits or costs of their non-GM counterparts.

but not the obligation—to exercise the option at any point during the validity period. We interpret the concept such that the decision maker has the right, but not the obligation, to authorise a new technology at any point during an infinite validity period.

Throughout our analysis, we demonstrate that a decision-making body aiming to maximise social welfare should release GM HR rapeseed lines immediately in a case in which MISTIC values are smaller than the actual irreversible social costs (I).

Reversible and irreversible incremental private and social benefits and costs

It is important to distinguish between reversible and irreversible incremental benefits and costs, particularly in terms of private (farmer), non-private (non-farmer citizens) and social (the sum of private and non-private) welfare effects. Reversible benefits and costs are only present for the period during which the farmer cultivates GM rapeseeds. Reversible benefits are defined as benefits of low tillage cultivation systems that are applicable due to the plants' HR characteristic (i.e. yield increase, reduction in cultivation costs due to fewer machinery hours and cheaper herbicide treatment). Conversely, irreversible benefits and costs are those that persist even if GM rapeseeds are no longer cultivated. We consider reduced CO_2 emissions due to lower fuel usage as irreversible benefits (DEMONT et al., 2004, SCATASTA et al., 2007). Irreversible costs might relate to possible negative effects on biodiversity, transfer of genes from GM rapeseeds to bacteria, outcrossing in wild or conventional relatives, human health hazards, biosafety regulation costs as well as development of weed resistance (GREEN, 2007, POWLES and YU, 2010). Irreversibility implies that once an action is taken, it is impossible to revert to the initial situation that prevailed before the action was taken. The possibility of irreversible costs for society following the introduction of genetically modified organisms (GMOs) in agriculture is regarded as a major reason for the reluctance in European society and politics to allow GMOs. *Table 14* summarises the reversible and irreversible incremental private and social benefits and costs for GM HR rapeseed production considered in this study. Furthermore, we include the symbols used throughout the text.

Table 14: Reversible and irreversible incremental private and social benefits and costs

		Private (farmer) aspects	**Non-private (non-farmer) aspects**	**Social aspects**	**Symbol**
Benefits/ hectare	Incremental, irreversible	n/a	Reduction in CO_2 emission	∑(private aspects + non-private aspects)	$\boldsymbol{J}$
	Incremental, reversible	Higher yield (10%), Reduction in cultivation costs (low tillage),	n/a		$\boldsymbol{W}$ (net benefits)
Costs/ hectare	Incremental, reversible	n/a	n/a		
	Incremental irreversible	n/a	possible negative effects for society (e.g. increasing health cost, loss in biodiversity)		$\boldsymbol{I}$

Source: Authors' own compilation

The real options approach is particularly relevant if the action (i.e. development, release, or adoption) is accompanied by irreversible costs. This is plausible to the extent that if all costs accompanying an investment decision are reversible, there would be no incentives to postpone the investment (provided that the immediate benefits exceed the costs) even if future benefits and costs are uncertain. However, irreversibility reduces the benefits. Consequently, the presence of irreversibility gives value to the possibility of postponing the decision and wait for further information regarding the hazards posed by the particular innovation.

Maximum incremental social tolerable irreversible costs (MISTICs)

The real options approach developed by Dixit and Pindyck (1994) considers the optimal time to invest (irreversible) sunk costs (S) in return for uncertain infinite reversible benefits of a project (W), given that W evolves according to a geometric Brownian motion (GBM), which can be written as;

$$dW = \alpha W dt + \sigma W dz \tag{11}$$

in which

$$dz = \varepsilon_t \sqrt{dt}, \varepsilon_t \approx N(0,1) \tag{12}$$

where α is the drift rate, dt is the change over time, σ is the variance parameter and dz is the increment of a Wiener process, which is independently and identically distributed according to a normal distribution with a mean of zero and a standard deviation of one. *Equation 11(11* implies that the project's current value is known, but future values are log-normally distributed with a variance that grows linear over time (SCHWARTZ and TRIGEORGIS, 2004).

Based on continuous claim analysis and dynamic programming, DIXIT and PINDYCK (1994) showed that it is optimal to invest if W exceeds not only the sunk costs S but the critical value W^*;

$$W^* = \frac{\beta}{(\beta - 1)} S \tag{13}$$

The latter can be derived by including uncertainty and irreversibility through the hurdle rate ($\frac{\beta}{(\beta-1)}$), which will be subsequently explained in more detail. As $\beta > 1$, the hurdle rate increases the critical value for the investment decision (W^*) compared with a classical investment decision criterion ($W_C^* = S$). To introduce MISTICs, we consider $S = I - J$. An option to introduce GM rapeseeds should be exercised if W is at least W^*. If W is less than W^*, the decision should be postponed.

In the context of GM crops, European society is concerned about potential but uncertain irreversible costs. However, based on the current state of knowledge, quantifying the social irreversible costs (I) caused by introducing GM HR rapeseeds appears unfeasible. But we can resolve *Equation 13* to focus on the critical value for I (I^*).

$$I^* = \frac{\beta - 1}{\beta} W + J \tag{14}$$

The new interpretation of the equation is that an option to introduce the GM HR rapeseed should be exercised if I is smaller than I^*. If I is greater than I^* the decision should be postponed. I^* is the real options decision criteria defined as MISTICs (WESSELER et al., 2007). With MISTICs we determine the upper limit of the sum of the irreversible social costs (J) and reversible net benefits (W) weighted by the hurdle rate until it would be socially optimal to immediately release an innovation e.g. HR GM rapeseed). Or if a technology is not released (as HR GM rapeseed) the MISTICs value can be seen as benefits the society is willing to sacrifice for the sake of not introducing GM rapeseed production.

Hurdle rate

The hurdle rate increases in accordance with the increasing volatility of previous gross margins, as we assume that past volatility makes future returns more risky and uncertain. We calculate the hurdle rate $\left(\frac{\beta}{1-\beta}\right)$ using gross margins per hectare for German conventional rapeseed production in Germany for 2007–2013;

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1 \tag{15}$$

where r is the risk free rate of return, δ is the convenience yield and σ is the volatility of W. The convenience yield (δ) is the difference between the risk-adjusted rate of return (μ) and the mean

$$\delta = \mu - \alpha \tag{16}$$

annual rate of return (α) (Dixit and Pindyck, 1994) and can be expressed as;

The risk-adjusted rate of return (μ) is calculated using the capital asset pricing model (CAPM) (HULL, 1999). The mean annual rate of return α can be determined as follows MUßHOFF and HIRSCHAUER

$$\hat{\alpha} = \left(\frac{\sum_{t=1}^{T} ln\left(\frac{w_{ha_t}}{w_{ha_{t-1}}}\right)}{n-1}\right) \tag{17}$$

(2003);

where w_{ha} represents the net incremental benefits per hectare per year that could have been achieved with GM rapeseeds in Germany at time t. For t, we consider the period 2007–2013.

Social incremental reversible net benefits (W_T) and social incremental irreversible benefits (J_T)

W_T and J_T are calculated as the discounted sum of annual incremental reversible net benefits (w) and annual incremental irreversible benefits (w), respectively, from the time released (T) until infinity. The release of an innovation follows an adoption process that needs to be considered for our calculation of discount.

Adoption

For agricultural crop innovations, the adoption process leads to an increase in the area allocated to the new variety over time. We assume that the adoption process follows an S-shaped curve (Griliches, 1957, Rogers, 2003), which can be formulated as;

$$\theta(t) = \frac{\theta_{max}}{(1 + e^{-(a+bt)})} \quad (18)$$

The parameters a and b can be estimated using nonlinear optimisation[17], where a is a constant, b is the rate of adoption and θ_{max} is the maximum level of adoption. We assume that θ_{max} refers to the last year of observation with respect to the adoption data used.

Social reversible net benefits (W_T)

W_T is the social incremental reversible net benefit, which equals social incremental reversible benefits minus social incremental reversible costs. The total annual value of W_T $[w(t)]$ under consideration of an adoption process is calculated as;

$$w(t) = w_{max}\theta(t) \quad (19)$$

with the maximum aggregated benefit under complete adoption (w_{max}) expressed as;

$$w_{max} = w_{ha} * h \quad (20)$$

where w_{ha} is the incremental reversible net benefits per hectare and h is the total area in Germany (in hectares) used for rapeseed cultivation.

The expected discounted present value of $w(t)$ from T until infinity (W_T) is calculated as;

$$W_T = \int_T^\infty w_{max}\theta(t)e^{-\mu t}dt \quad (21)$$

Social incremental irreversible benefits (J_T)

Similar to the process used to derive W, we determine J as;

$$J_T = \int_0^\infty j_{max}(t)\theta(t)e^{-\mu t}dt \quad (22)$$

$$j_{ha} = \chi g_{nt} \quad (23)$$

where χ represents external costs per tonne of CO_2 emissions and g_{nt} is the amount of reduced CO_2 equivalent due to low tillage cultivation.

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[17] Alternatively, we estimated a und b using linear regression and obtained similar results.

Option value

The possibility of waiting for further information and thus delaying the exercise of an option is an essential criterion within the financial interpretation of real options. Transferring this to our analytical problem, the option to act or deregulate has a value itself as it allows the owner a possibility to reduce losses by postponing the action.

The value of an option to invest with uncertain revenues but known costs has the form

$$F(W) = AW^{\beta} \tag{24}$$

where A is a constant that can be determined as follows (Dixit and Pindyck, 1994);

$$A = (W^{*} - I)/(W^{*})^{\beta} \tag{25}$$

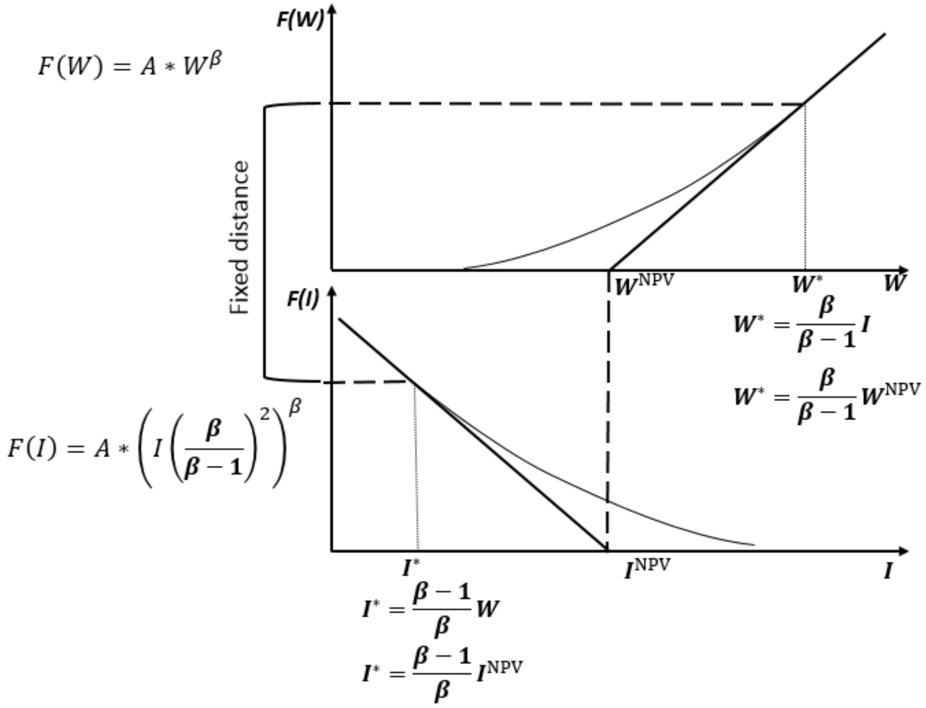
For MISTICs where we determine I^{*} instead of W^{*}, we can reformulate *Equation 25(25* as;

$$A = (W - I^{*})/(W)^{\beta} \tag{26}$$

Figure 8 shows the relationship between the optimal value to invest (W^{*}) and the MISTICs value (I^{*}) determined by the real options approach as well as the relationship between I^{NPV} (investment costs considered in positive terms) and W^{NPV} determined with NPV calculation.

According to the NPV investment decision, it is optimal to invest if $I^{\mathrm{NPV}} \leq W^{\mathrm{NPV}}$. $I^{\mathrm{NPV}} = W^{\mathrm{NPV}}$, as depicted in Figure *8* denotes the investment threshold. Based on this threshold value, W^{*} and I^{*} can be determined by the factors $\frac{\beta}{\beta-1}$ and $\frac{\beta-1}{\beta}$, respectively. The option value for W^{*} ($F(W^{*})$) and I^{*} ($F(I^{*})$) are equal.

Figure 8: Relation between the option values F(I) and F(W)



Source: Authors' own compilation

Data

For the ex-ante assessment of future revenues, we assume that the benefits derived from GM HR rapeseed cultivation in Germany will equal the related benefits observed in countries where GM HR rapeseed cultivation has already been deregulated.

We completed a time series for the incremental, achievable gross margins per hectare with respect to rapeseed cultivation in Germany for the period 2007–2013 for a situation in which GM HR rapeseed cultivation had been adopted. We compare conventional rapeseed cultivation incorporating ploughing to that using a low tillage cultivation system, as the latter would be possible with GM HR rapeseed seeds. *Table 15* list the single considered cultivation steps in each system.

Table 15: Cultivation steps for conventional and GM HR rapeseeds production

Conventional	**GM HR (Low tillage)**
Soil sample (every 5th year)	Soil sample (every 5th year)
Fertilization	Fertilization
Ploughing	
Harrowing	
Seeding	Seeding

Herbicide application (500 g Metazachlor, 500 g Dimethenamid and 85 g Clomazone)	Herbicide application (1088 g Glyphosate)
Spray application (fungicide)	Spray application
Growth control	Growth control
Fertilization	Fertilization
Growth control	Growth control
Fertilization	Fertilization
Spray application (fungicide, insecticide)	Spray application
Harvest	Harvest
Transport	Transport
Chalk	Chalk
Tillage	
Tillage	

Source: Authors' own compilation

The total costs for rapeseed cultivation depend on the prices of fertilizer, herbicides, fungicides, insecticides, seed, machinery, fuel, insurance and seed drying. Information on prices was supplied by the State Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt[18] (LLFG, 2014). Only the direct cost for herbicide application (herbicide and associated application costs) differs between conventional and low tillage cultivation systems. We adjusted herbicide costs by annual prices for glyphosate (BAYWA, 2014). Variable machinery costs are taken from Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL). In addition, based on BROOKES and BARFOOT (2014), we assumed an annual yield surplus of 10% as incremental reversible benefits. However, we will also present results of our model without a 10% yield increase since it remains uncertain if there will be yield differences between a GM HR and an intensive conventional rapeseed production.

The average conventional rapeseed yield (DESTATIS, 2014b) as well as the cultivation area (DESTATIS, 2014a) in Germany is obtained from the DESTATIS online database. Rapeseeds' prices are based on nearby futures prices from the MATIF (AHDB, 2014). We ignore potential shifts in demand or price changes due to GM rapeseed production. All monetary data are deflated using 2013 as the base year and annual inflation rates from DESTATIS (2014c).

Concerning the environmental impact from the introduction of GM HR technology, we consider reduced CO_2 emissions due to less cultivation steps (*Table 15*). The differences in CO_2 emissions between conventional and low tillage cultivation are, on average, 160.89 kg CO_2 equivalent/ha/a. The value was derived using the KTBL dataset and the ENZO2 Greenhouse Gas Calculator (IFEU, 2015). We

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[18] Saxony-Anhalt is one typical rapeseed production area in Germany.

evaluated the CO_2 equivalent using € 65.18/tonne of carbon (C)[19] following the conclusions in TOL (2011) on the social evaluation of carbon. With the factor 0.2727 to convert tonnes of CO_2 into tonnes of C (EPA, 2004) we approximate environmental benefits from reduced CO_2 emission with € 2.86/ha on average. *Table 16* summarises the different cultivations systems in terms of revenues, cost, incremental reversible private benefits and incremental irreversible non-private benefits over the years 2007–2013.

Table 16: Cultivation costs and benefits

Year	**Rapeseed production revenue (€/ha)**		**Rapeseed production costs (€/ha)**				
	GM HR	**Conventional**	**GM HR**	**Conventional**	**Incremental reversible private (farmer) benefits (€/ha)**		**Incremental irreversible non-private (non-farmer) benefits (€/ha)**
					With yield increase	**W/o yield increase**	
2007	1010.65	918.77	457.32	574.27	208.83	116.95	5.81
2008	1667.26	1515.69	544.47	639.01	246.11	94.54	5.81
2009	1516.28	1378.44	647.34	738.89	229.39	91.55	5.79
2010	1231.04	1119.12	629.05	705.18	188.04	76.13	5.82
2011	1389.09	1262.81	565.29	645.31	206.3	80.02	5.79
2012	1831.58	1665.08	593.22	682.65	255.94	89.43	5.77
2013	2052.97	1866.34	612.19	709.34	283.78	97.15	5.76

Source: Authors' own calculation, see text

The incremental private benefits are quiet high compared to empirical based incremental benefits in other studies. BROOKES and BARFOOT (2014) calculated average annual incremental benefits from GM

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[19] The original value is 80 USD/tonne of C and the considered exchange rate 1 USD = 0.8148 EUR

HR rapeseeds for Canadian (and similar for American) farmers of $/ha: 52. QAIM (2009) even reports that net benefits from HR rapeseeds have been small or partly negative to Canadian and American farmers since the seed premium payed to the seed company was similar to the benefits. For our ex-ante approach we calculated potential benefits and ignored seed premiums, which can be very different according to trait or region. Furthermore, a 10% increase yield increase—as observed by BROOKES and BARFOOT (2014)—has an high impact in absolute terms, considering that the average rapeseed yields for Germany are around twice as high compared to U.S. and Canada (FAO, 2015). Eventually, since our gross margins are constructed and not empirical reported they might overestimate potential savings. However, our estimated increase in gross margin of ca. 25% is below the increase 40% assumed by (BREUSTEDT et al., 2008).

To estimate the speed and magnitude of future adoption of GM technology, we use the adoption information for hybrid rapeseeds in Germany. The data shows the annual line and hybrid rapeseed cultivation area for the period 1996–2014 (KLEFFMANN-GROUP, 2012). Even though hybrid and GM rapeseed innovations differ in breeding technology, using these data enables us to estimate an adoption function for a recent yield increasing innovation[20] for the German rapeseed market. However, for the adoption of GM HR rapeseeds further market and farming aspects such as consumer preferences for conventional compared with GM rapeseeds, segregation cost or price differences between conventional and GM rapeseeds, expected liability from cross pollination, producers' neighbours attitude towards GM technology, technology fees and farm characteristics will be important (BREUSTEDT et al., 2008).

For the ex-ante perspective of our study, we assume the absolute area (in hectares) used for rapeseed cultivation will remain constant at the average level for the period 2010–2013. We assume that only the relative amount of GM rapeseed and conventional rapeseed will change over the course of the adaptation process.

The risk-free rate of return of 3.37% is the average interest rate from 2007–2013 for German 30-year federal bonds (DEUTSCHE BUNDESBANK, 2014). As a broad index, we used the average revenue per hectare for special crop farms in Germany published by the German Federal Ministry of Food and Agriculture covering 2003–2013 (BMELV, 2015). Therefore, we assume this revenue level as the revenue to be achieved by an average crop farmer as the risk is decreased by a more diverse crop production portfolio. In comparison, in a finance-based analysis, broad index stocks such as S&P 500 or DAX are used.

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[20] Hybrid rapeseeds were introduced to the German market in 1996.

Results and discussion

Our results suggest that during 2007–2013, the average net incremental reversible private benefits of GM HR rapeseeds compared with their conventional counterpart would have been € 242.58/hectare/year.

The adoption function was determined as;

$$\theta(t) = \frac{0.84}{(1 + e^{-(-2.88+0.29t)})} \tag{27}$$

To apply the real options concept, we estimated a risk-adjusted rate of return (μ) of 8.19%, a drift rate in net incremental benefits (α) of 4.08% and a hurdle rate of 1.58. Assuming a yield increase of 10% we estimated W_{2014} and R_{2014} as € 1.73 billion and € 39.308 million, respectively. We determined MISTICs as € 1.115 billion for German society in 2014, based on *Equation 14*. Thus, immediate introduction of GM HR rapeseeds in Germany in 2014 would have been economically justified if the actual social irreversible costs did not exceed this value. MISTICs are found to be € 976.99 per hectare[21] cultivated with rapeseeds and € 13.80 per citizen. The mentioned results and the model results without a 10% yield increase are summarized in *Table 17.* Without yield increase—a realistic scenario due to an already intensive conventional rapeseed production with high yield in Germany—MISTICs and possible forgone benefits are about half.

Table 17: Monetary effect GM HR rapeseed cultivation in Germany

	Society	**Per citizen**	**Per household**	**Per hectare rapeseeds**
MISTICs for 2014 (for an infinite time horizon) in € with yield increase	1 115 173 589	13.8	27.64	976.99
MISTICs for 2014 (for an infinite time horizon) in € w/o yield increase	588 052 775	7.28	14.58	396.1
Possible forgone social benefits in 2013 in € with yield increase	416 026.68	0.005	0.01	286.58

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[21] MISTICs per hectare do not consider an adoption process and assume a rapeseed cultivation every third year.

Possible forgone social benefits in 2013 in € w/o yield increase	142 421.9	0.002	0.004	99.94

Note: Maximum incremental social tolerable irreversible cost (MISTICs) are calculated for German society comprising a population of 80.82 million citizen (DESTATIS, 2014d), 40.34 million households (EUROSTAT, 2014) and a total rapeseed cultivation area of 1.47 million hectares. To calculate a value per hectare rapeseeds we assume that rapeseed cultivation on the same field is only possible every third year.

Source: Authors' own calculation

The option value $[F(W)]$ of € 249.058 million (based on *Equation 24*) can be interpreted as the monetary value of German society introducing GM HR rapeseed cultivation at some point, i.e. it can be regarded as the societal value of the possibility of access to this technology. Accordingly, the government could use this value as a benchmark for making allocation decision with respect to research funds.

Previous studies derived MISTICs values in a manner similar to our estimates. For the introduction of GM HR sugar beets in Europe, DEMONT et al. (2004) determine MISTICs at € 169 million overall and € 1.1 per European household. WESSELER et al. (2007) determine MISTICs for GM insect-resistant (IR) and HR maize for different European countries. For IR maize, they found values ranging from € 157.34/hectare for Greece to € 268.73/hectare for Spain. For HR maize, they found values ranging from € 14.97/hectare for Belgium to € 134.95/hectare for Spain. These studies are based on a similar real options concept as used in this study; however, they differ with respect to their modelling assumptions including the determination of the incremental benefits, the adoption process and the economic evaluation of carbon. It is important to point out that in general MISTICs for single GM crops are quite small but. For a more general socio-economic assessment of GM crops the sum of MISTICs for all different possible GM crops needs to be considered.

The economic valuation of environmental impacts using carbon emission-related proxy variables remains challenging. As described earlier, we value carbon using the proxy variables suggested by TOL (2011) at € 65.18/tonne of C. Additionally, we tested the robustness of our model using alternative price assumptions. First, we assumed a price of €5.68 for one tonne of CO_2 equivalent, as this is the average trading price at the German Emissions Trading Authority for the first six-month period of 2014 (DEHST, 2014). Second, we set the price for one tonne of CO_2 at € 77.4 as suggested by PRETTY et al. (2000)—a value that has been used in other MISTICs-related studies (DEMONT et al., 2004, WESSELER et al., 2007). Using these prices results in derivation of MISTICs (with yield increase) per citizen of € 12.05 and € 14.57, respectively.

Conclusion

This study evaluated the positive economic and environmental effects of introducing GM HR rapeseeds in the German market. By applying a real options approach and considering flexibility, irreversibility and uncertainty, we quantified the ex-ante value and estimate the MISTICs as € 13.8 per German citizen. Further, we estimate an option value $[F(W)]$ of € 249.058 million for the possibility of access to the technology for German society. These values provide important information for decision makers. However, it remains their task to weigh these benefits against the potential irreversible hazards from immediate deregulation of GM HR rapeseed cultivation. In addition, regulatory decisions are influenced by complex set of political factors that go well beyond the consideration of social benefits and costs. Thus, the European regulations on GM crops reflects different conflicting political interests and powers, which addresses GM crops in general and not specifically GM HR rapeseeds. Still, the combination of low MISTICs value of GM HR rapeseeds and a generally negative consumer attitudes towards GMOs (EUROPEAN COMMISSION, 2010a) indicates a low political probability for the approval of GM HR rapeseeds in the near future. Regarding MISTICs, we only calculated a threshold value. The remaining question is whether the actual incremental irreversible costs will exceed the MISTICs. The next step in the process of finding the socially optimal solution requires determination of whether consumers are willing to bear the MISTICs as a price for not introducing GM HR rapeseeds.

Empirical Study 4
High-Yielding Genetically Modified Wheat in Germany: Socio Economic Assessment of its Potential

The content of this empirical study was published as a journal article:

Wree, P. and J. Sauer (2016). High-Yielding Genetically Modified Wheat in Germany: Economic Impact Assessment of its Potential. *Agricultural Economics Review*, 17(1): 80.

Abstract

A novel genetically modified (GM) wheat variety (HOSUT) shows yield increasing potential of ca. 28%. We apply the real options concept of Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) to conduct an ex-ante assessment of the potential economic impact of HOSUT wheat for Germany. In different scenarios cost and benefits associated with the adoption of this yield increasing innovation are analyzed. Our results indicate that not authorizing HOSUT wheat is correct if German society values the hazard of social irreversible costs from this GM technology to be between € 7.75 and € 12.78.

Keywords: Real options, GM wheat, yield increase, uncertainty, irreversibility

JEL classification: Q12, Q15, Q16

Introduction

Transgenic or genetically modified (GM) crops offer various potential benefits (Carpenter and Gianessi, 1999, Qaim, 2009, Zilberman et al., 2010) but also raises society's concerns about potential irreversible health and environmental hazards (Weale, 2010). The consideration of both is important for deregulation decisions by society's institutions (e.g. European Commission). The regulatory challenge of whether to deregulate or ban for GM high-yielding HOSUT wheat variety is the motivation of this research.

20% of the world's calorie and protein demand is met by wheat (Shiferaw et al., 2013). By that wheat is one of the most important food for human nutrition and is crucial for food security. In 2012 the global wheat production was ca. 670 million tons. The world's biggest producers are China, India and the U.S.A.. With ca. 3% of the global production is Germany the worlds' 9th biggest wheat producer (FAO, 2015). A sustainable and at the same time increasing global wheat production is essential to cope with the challenges of food security for a growing human population (Reynolds et al., 2009). Numerous innovations in agricultural production and breeding productivity guaranteed a stable yield increase in the past years. Breeding techniques have developed from weak forms of selection, to more precise selection in combination with mutation, inbred, hybrid and biotechnology or genetically modified organism (GMO). Only the latter technology raises broad concerns across societies, especially in the EU (Gaskell et al., 2010).

Researchers at the publically funded IPK[22] in Gatersleben, Germany, used genetic modification (GM) technology to develop novel winter wheat lines (HOSUT) with high yield potential. The researchers were able to introduce the barley sucrose transporter HvSUT1, controlled by the barley Hordein B1 promoter, into the conventional winter wheat line; Certo. The results of the breeding experiment were different HOSUT wheat lines. Three of the HOSUT wheat lines were grown over three years in micro-plots under field-like conditions in semi-controlled glass houses. Grain yield per plot significantly increased by average 28%, together with higher total protein yield, but lower protein concentration, and higher iron and zinc concentration (both increased by ca. 30%) when compared to the non-transformed control line (Saalbach et al., 2014).

Independent from the state of development of HOSUT wheat, the introduction of GM wheat lines into the European Union or German market seems to be very unlikely under the current social and political acceptance of GMOs. However, an economic impact assessment can help to structure the political decision about the support of research and development of the innovation. In this study we will do an ex-ante economic impact assessment for a 28% yield increasing wheat innovation for Germany. The focus on Germany stems from the fact that so far HOSUT wheat lines have only be tested under German climate conditions. We will analyze the potential economic impact potential of

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[22] LEIBNIZ-INSTITUT FÜR PFLANZENGENETIK UND KULTURPFLANZENFORSCHUNG

an immediate release of HOSUT wheat considering private and social reversible and irreversible costs and benefits and determine Maximum Incremental Social Tolerable Irreversible Costs (MISTICs). The theoretical concept of MISTICs is based real options (RO) theory. RO theory, as developed by McDonald and Siegel (1986), Dixit and Pindyck (1994), and Schwartz and Trigeorgis (2004) focuses on the value of an option to invest under uncertain benefits,

The concept of RO is empirically applied for ex-ante assessments of different agricultural investment, such as in irrigation systems (Carey and Zilberman, 2002, Michailidis et al., 2009), ethanol plants (Pederson and Zou, 2009), and in precision agricultural machinery (Tozer, 2009). Under different considerations and assumption, different studies use MISTICs or similar RO approaches to evaluate GM crop breeding innovation. Wesseler et al. (2007) calculate MISTICs for the cultivation of GM maize in Europe. For different countries and traits they find values between € 14.97/hectare and € 268.73/hectare. With a similar approach Demont et al. (2004) conclude that a ban on GM sugar beet in the EU is correct, if EU households value the possibility of annual irreversible costs from that technology at minimum with € 1.1. Considering health aspects for Indian society from Golden Rice Wesseler and Zilberman (2014) apply RO to conclude that annual perceived costs from Golden Rice have to be at least USD 199 million per year to explain the current ban of the technology. However, the majority of existing literature on the economic assessment on GM crops takes an ex-post—after commercial introduction—perspective. Detailed analytical overviews about those ex-post studies are given by Barrows et al. (2014a) , Carpenter (2013), Finger et al. (2011), Klümper and Qaim (2014) and Zilberman et al. (2010). Different to other major crops, no GM trait for wheat was ever commercialized and thus, GM wheat varieties are not content of current ex-post assessments. Existing studies on GM wheat analyze the potential economic welfare effect of GM herbicide tolerant (HT) wheat in Canada (Berwald et al., 2006, Johnson et al., 2005, Wilson et al., 2008). The development of high-yielding GM wheat is a very reasoned and promising breeding innovation and has not been analyzed with an economic impact assessment so far.

For our model we make assumptions based on Saalbach et al. (2014) and combine these with findings about the wheat cultivation situation in Germany. Within different scenarios we extent the model to potential CO_2 emissions savings and weighted those economically. Eventually we will derive MISTICs on three different scenarios, which will consider the potential private and social benefits and costs.

The paper proceeds as follows. The next section explains the motivation for scenario structure of benefits and costs, chosen for this study, and develops the theoretical concept of MISTICs. Thereafter data information is supplied, followed by the presentation of the results and their discussion. The final section summarizes our findings and suggests potential conclusions.

Model and Method

When an innovative technology is filed for deregulation, decision making bodies as the European Council and European Commission can either approve or decline the request. The objective in making such a decision should be to maximize society's welfare (V), which can be described as;

$$maxV = (0, W + J - I) \tag{28}$$

W are the discounted total future incremental[23] reversible net benefits, and J and I are the discounted total future irreversible benefits and costs associated with the deregulation of the technology, respectively. However, the determination of W, J and I is often challenging and sometimes unfeasible.

The net present value (NPV), as the standard neoclassical decision making criterion will suggest to deregulate an innovative technology if the expected social benefits are greater than the social costs. This approach neither considers uncertainty and irreversibility, nor the possibility to postpone the decision. In our model we use an ex-ante assessment model based on RO theory that explicitly considers these aspects.

The theoretical basis for our analysis is the RO approach by DIXIT and PINDYCK (1994). Based on this approach, we designed our economic assessment model as an information or decision making tool for politicians or decision making bodies. The output of our model will be a value for MISTICs, which then can be used as a decision criterion. We apply our conceptual framework to the situation where a seed company applies for deregulation of HOSUT wheat in the EU. Similarly to an option to invest in finance, decision making bodies can approve such an application immediately, or postpone the decision and wait for further information.

MISTICs are based on an American type of call option. In finance, an American call option gives the holder the right, but not the obligation to exercise an investment at any point in time. Our interpretation of the concept will be that the decision maker has the right, but not the obligation to authorize a new technology at any point in time. Further we assume that the option will never expire.

Prior to the explanation of theoretical concept of MISTICs we will introduce the scenarios we use to compare and distinguish between reversible and irreversible incremental private and social benefits and cost.

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[23] As "incremental" we consider the difference between HOSUT wheat and alternative conventional (non-GM) wheat.

Scenario I and II

We introduce three different scenarios (I, II.I and II.II), which will consider the potential benefits to wheat farmers and society, if the introduction of the new technology is combined with political conditions, i.e. decompensation areas (summarized in *Table 18*).

Scenario I (constant area) only considers incremental benefit to wheat farmers due to yield increase on the area cultivated with HOSUT wheat. Scenario I is typical for first generation GM products, such as insect resistance and herbicide tolerant traits, where benefits are manly on the producer and not on the consumer side (MOSCHINI and LAPAN, 2006).

Scenario II (constant quantity) considers incremental benefits to society and cost reduction to farmers due to a decompensation of cultivation area. GREEN et al. (2005) presented biodiversity advantages of decompensation areas in combination with high yield farming compared to low yield farming without decompensation area. Their findings supports the political idea of decompensation areas and indicates increasing biodiversity on decompensated areas as an additional non-private benefit. We assume that if HOSUT wheat is cultivated there will be a cultivation and a decompensation zone. The cultivation zone will be a percentage part of one hectare (ha) just as large that the absolute production in tons per ha of HOSUT wheat will be equal to the absolute production of one ha conventional wheat. The decompensation zone will be the remaining percentage part of one ha. In numbers, if HOSUT wheat has 28% higher yields per ha than conventional wheat, 0.78125 ha HOSUT cultivation zone is necessary to generate the same absolute yield as 1 ha conventional wheat crop. Consequently, 0.21875 ha are decompensation zone. Decompensation of agricultural production area does have different environmental benefits and by that it has a positive impact on social benefits. As benefits form decompensation we consider reduction in inputs, such as fertilizer, pesticides and fuel weighted by their CO_2 equivalent. Other benefits that might occur, such as increase in biodiversity are not considered. One can think about the scenario II as a regulation in order to transfer benefits of yield increasing GM technology to society. The decompensated land can either be not cultivated at all or with legumes, which would enrich the soil with nitrogen (N) for next year's crop. Therefore, we distinguish between scenario II.I with no cultivation and scenario II.II with legumes cultivation on the decompensated land. The scenario specifications are summarized in *Table 18.*

Table 18: Scenario specification

Scenario		**0**	**I**	**II.I**	**II.II**
Wheat variety		Certo	HOSUT	HOSUT	HOSUT
Decompensation for HOSUT wheat		-	-	+	+
Legumes cultivation on decompensation zone		-	-	-	+
Incremental benefits to farmer	Yield increase/ha	-	+	-	-
	Cost reduction (less cultivation cost/ha)	-	-	+	+
	Legumes (cost savings for N for next season)	-	-	-	+
Incremental benefits to society	Decompensation (reduced cultivation area)	-	-	+	+
	Legumes (CO_2 saving compared to synthetic N production)	-	-	-	+

Note: Scenario 0 represents conventional wheat production and is the reference for the percentage yield increase of HOSUT wheat. '+' indicates that the specification is included in the specific scenario.
Source: Authors' own compilation

Reversible and irreversible incremental private and social benefits and costs

It is important to distinguish between reversible and irreversible incremental private (farmer), non-private (non-farmer) and social (as the sum of private and non-private) benefits and costs. Reversible benefits or costs are those that stop if the farmer stops planting HOSUT wheat. E.g. increasing yield, less production costs per ha, and lower price per ton. Irreversible benefits or costs are those that still persist after HOSUT wheat is no longer cultivated. Following SCATASTA et al. (2007) and DEMONT et al. (2004) we consider irreversible benefits as those resulting from reduced CO_2 emissions. Irreversible costs might be possible negative effects on biodiversity, transfer of genes from HOSUT wheat to bacteria or wild and conventional relatives, human health hazard, and biosafety regulation costs. Irreversibility implies that once an action is taken it is impossible to revert back to the initial situation as it was before the action. The possibility of irreversible costs to society associated with an introduction of GM crops is a major reason for the reluctant attitude towards GMOs in European society and politics.

The RO approach is of particular importance if the action is accompanied by irreversible costs. This is plausible, in so far, that if all costs that accompany an investment decision would be reversible, there would be no incentive to postpone the investment (provided that the immediate benefits exceed the costs), even if future benefits and costs are uncertain. Consequently, the presence of irreversibility reduces the benefits and gives a value to the possibility to postpone the decision and wait for the arrival of more information about the innovation's hazard (ARROW and FISHER, 1974).

We consider incremental benefits and costs for estimating the welfare effects. The incremental effect is determined by the difference between the benefits or costs from GM crops minus the benefits or costs of their non-GM alternative counterpart. *Table 19* summarizes the reversible and irreversible incremental private and social benefits and costs for HOSUT wheat production, which we accounted for or which are seen as irrelevant. Further it includes the symbols we will refer to throughout the text.

Table 19: Scenario I and Scenario II: Incremental costs and benefits

			Private (farmer) aspects	**Non-private (non-farmer) aspects**	**Social**	**Symbol**
Scenario I	Benefits/ ha	Incremental irreversible	n/a	n/a	∑(private + non-private) aspects	$\boldsymbol{J}$
		Incremental reversible	Higher yield (28%)	n/a		$\boldsymbol{W}$ (net benefits)
	Costs/ha	Incremental reversible	Lower price for less quality (lower protein content); higher absolute handling costs	n/a		
		Incremental irreversible	n/a	Possible negative effects for society		$\boldsymbol{I}$
Scenario II	Benefits/ ha	Incremental irreversible	n/a	Input reduction due to decompensation	∑(private + non-private) aspects	$\boldsymbol{J}$
		Incremental reversible	Less cultivation cost; less fertilizer costs due to legumes cultivation (scenario II.II)	n/a		$\boldsymbol{W}$ (net benefits)
	Costs/ha	Incremental reversible	Lower price for less quality (lower protein content); higher absolute handling costs	n/a		
		Incremental irreversible	n/a	Possible negative effects for society		$\boldsymbol{I}$

Source: Authors' own compilation

Real options

The RO approach developed by Dixit and Pindyck (1994) is an extension of the classical NPV decision criteria. RO consider the optimal time to invest (irreversible) sunk costs (S) in return for uncertain infinite reversible net benefits of a project (W), given that W evolves according to a Geometric Browian Motion (GBM) as follows;

$$dW = \alpha W dt + \sigma W dz \tag{29}$$

with

$$dz = \varepsilon_t \sqrt{dt}, \varepsilon_t \approx N(0,1) \tag{30}$$

where α is the drift rate, dt is the change over time, σ is the variance parameter and dz is the increment of a Wiener process. $dW=\alpha W dt+\sigma W dz$ implies that the project's current value is known, but future values are log-normally distributed with a variance that grows linear over time (SCHWARTZ and TRIGEORGIS, 2004).

Social reversible net benefits (W_T) and social incremental irreversible benefits (J_T)

W_T and J_T are calculated as the discounted sum of annual incremental reversible net benefits (w) and annual incremental irreversible benefits (w), respectively, from the time released (T) until infinity. The release of an innovation follows an adoption process. For agricultural crop innovations, the adoption process leads to an increase in the area allocated to the new variety over time.

Adoption

We assume that the adoption process follows an S-curve (ROGERS, 2003) with the logistic form;

$$\theta(t) = \frac{\theta_{max}}{\left(1+e^{-(a+bt)}\right)} \tag{31}$$

The parameters a and b can be estimated with nonlinear optimization[24]. Where a is a constant, b is the rate of diffusion or adoption and θ_{max} is the maximum level of adoption in percent.

Social reversible net benefits (W_T)

W_T are the social incremental reversible net benefits, which equals social incremental reversible benefits minus social incremental reversible costs.

$$W_T = \int_T^{\infty} w(t) e^{-\mu t} dt \tag{32}$$

where

$$w(t) = w_{max}\theta(t) \tag{33}$$

with $\mathrm{w}_{\mathrm{max}}$ being the maximum annual average aggregated reversible net benefit under complete adoption.

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[24] Alternatively, we estimated a und b with linear regression and received similar results.

Social reversible net benefits for scenario I, II.I, and II.II

For the descried scenarios we determine different total social reversible net benefits (W_T) with different social reversible net benefits per hectare (w_{ha}).

$$w_{ha_I} = y_{conv.} * \iota_{HOSUT} * (p_{conv.} - \kappa_{HOSUT} p_{conv.}) - (\Delta h_{HOSUT}) - c_{wheat} - (y_{conv.} * p_{conv.} - c_{wheat}) \quad (34)$$

with $y_{conv.}$ being the yield per ha of the conventional wheat variety, ι_{HOSUT} represents the yield increasing effect of HOSUT (1.28), $p_{conv.}$ being the price of the conventional wheat variety and κ_{HOSUT} represents the price reduction of HOSUT due to lower quality compared to the conventional wheat variety (0.05). Cultivation costs per ha of conventional wheat are considered by c_{wheat}. The values for $y_{conv.}$, $p_{conv.}$ and c_{wheat} are the three years average (from 2010 to 2013) y and p for German wheat producer. Further, increasing harvest cost per ha, that follow higher yield, are considered with Δh_{HOSUT} ($\Delta h_{HOSUT} = h_{HOSUT} - h_{conv.}$). With h_{HOSUT} being the harvest cost for wheat with a yield level as we assume for HOSUT wheat and $h_{conv.}$ being the harvest cost for conventional wheat.

For scenario II.I

$$w_{ha_{II.I}} = \left((1 - \lambda_{HOSUT}) * y_{conv.} * \iota_{HOSUT} * (p_{conv.} - \kappa_{HOSUT} p_{conv.}) - (\Delta h_{HOSUT}) - c_{wheat}\right) - (y_{conv.} * p_{conv.} - c_{wheat}) \quad (35)$$

with λ_{HOSUT} represents the land reduction factor (0.21875).

For scenario II.II

$$w_{ha_{II.II}} = w_{ha_{II.I}} + n_p \quad (36)$$

$$n_p = \lambda_{HOSUT} * (N_{legumes} p_N - c_{legumes} + c_{nitrogen_{application}}) \quad (37)$$

with $N_{legumes}$ being the amounted of fixed nitrogen (N) by legumes cultivation in kg per ha, p_N being the price for N per kg and $c_{legumes}$ being the cost of cultivation of legumes per ha. Further, the cost for the nitrogen application ($c_{nitrogen_{application}}$) by the end of the growing season, for preparing the next year crop, can be saved. The nitrogen effect (n_p) in scenario II.II includes impact of legumes cultivation on private and social benefits. For private benefits we consider that the farmer will produce N with the cost of legumes cultivation on the decompensation zone. Alternatively, the farmer would buy synthetic N. Further the farmer can save N application costs on the area cultivated legumes. Thus, we account the quantity the farmer produces times the price of N minus the production cost plus the N application cost as annual private benefits.

Social irreversible benefits ($\boldsymbol{J_T}$)

Similar to W, J can be determined as;

$$J_T = \int_T^{\infty} j(t)e^{-\mu t}dt \tag{38}$$

where

$$j(t) = j_{max}\theta(t) \tag{39}$$

with $\mathrm{j_{max}}$ being the maximum annual average aggregated irreversible benefit under complete adoption.

Social irreversible benefits for scenario I, II.I, and II.II

The social incremental annual irreversible benefits per ha $(\mathrm{j_{ha}})$ are different within the scenarios as well . For scenario I no $\mathrm{j_{ha}}$ are considered and for scenario II.I $\left(\mathrm{j_{ha_{II.I}}}\right)$ and II.II $\left(\mathrm{j_{ha_{II.\mathit{II}}}}\right)$ they are approximated by;

$$j_{ha_{II.I}} = \chi\lambda_{HOSUT}g_{wheat} \tag{40}$$

$$j_{ha_{II.II}} = \chi(\lambda_{HOSUT}(\,g_{wheat} - g_{legumes} + \zeta N_{legumes})) \tag{41}$$

where χ represents external costs per ton CO_2 emissions, g_{wheat} and $g_{legumes}$ being the CO_2 equivalent per ha of wheat and legumes production, respectively, and ζ represents CO_2 equivalent in kg for the synthetic production of one kg N.

Maximum Incremental Social Tolerable Irreversible Costs (MISTICs)

DIXIT and PINDYCK (1994) showed that it is optimal to invest if W exceeds not only S but also the critical value $W^*(\mathrm{W} > \mathrm{W}^*)$, which can derived by including uncertainty through the hurdle rate $\left(\frac{\beta}{(\beta-1)}\right)$, which will be subsequently explained in more detail.

$$W^* = \frac{\beta}{(\beta-1)} S \tag{42}$$

Since $\beta > 1$, the hurdle rate increases the critical value for the investment decision (W^*) compared to a NPV investment decision criterion. An option to introduce HOSUT wheat should be exercised if $\mathrm{W_T}$ is at least W^*. If $\mathrm{W_T}$ is less than W^*, the decision should be postponed.

To introduce MISTICs we consider $S = I - J$. In the context of GM crops society in Europe is concerned about potential but uncertain irreversible cost. Albeit, the quantification of social irreversible cost (I), caused by the introduction of HOSUT wheat, seems to be unfeasible with our current state of knowledge. But we can resolve *Equation 43(43)* in order to find a critical value for I (I^*).

$$I^* = \frac{\beta - 1}{\beta} W_T + J_T \tag{43}$$

The interpretation of *Equation 43* is that an option to introduce HOSUT wheat should be exercised if I is smaller than I^*. If I is larger than I^* the decision should be postponed. I^* is the RO decision criteria defined as MISTICs (Wesseler et al., 2007). With MISTICs we identify the upper limit of the sum of irreversible social costs J_T and $\mathrm{W_T}$, weighted by the hurdle rate, until it would be social optimal to immediate release an innovation (HOSUT wheat). Alternatively, if a technology is not released—as GM wheat—the MISTICs value can be seen as the benefits society is willing to sacrifice for the sake of not having this technology—GM wheat production.

Hurdle rate

The hurdle rate increases in accordance with the increasing volatility of previous gross margins, as we assume that past volatility makes future returns more risky and uncertain. We calculate the hurdle rate using average gross margins per ha for German wheat production from the years 2004–2013.

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1 \tag{44}$$

where r is the risk free rate of return, δ the convenience yield and σ is the volatility of W_T . The convenience yield (δ) is the difference between the risk adjusted rate of return μ and the mean annual rate of return α (Dixit and Pindyck, 1994); this can be expressed as follows;

$$\delta = \mu - \alpha \tag{45}$$

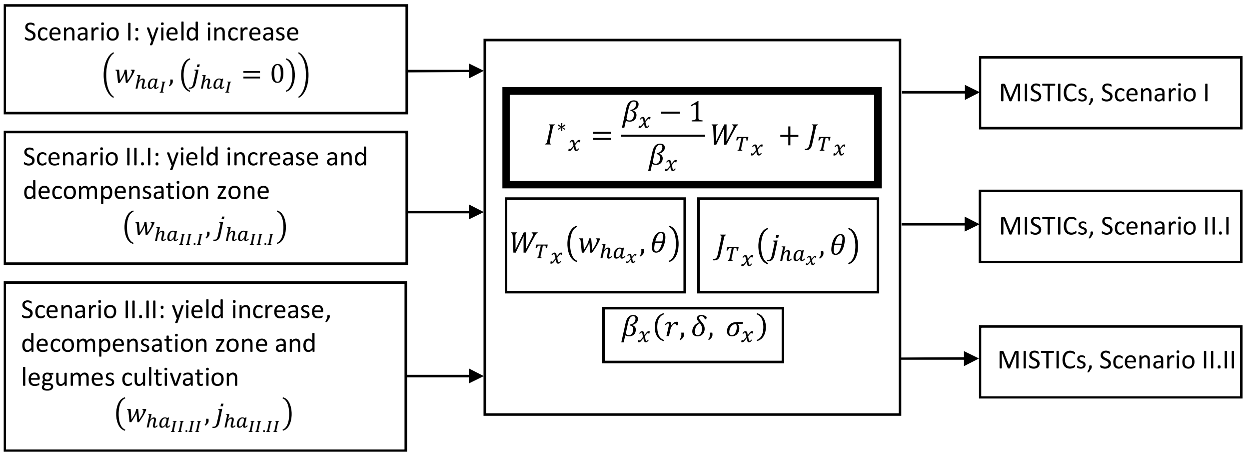
The risk adjusted rate of return μ is calculated using the Capital Asset Pricing Model (CAPM) (HULL, 1999) The mean annual rate of return α can be determined following MUßHOFF and HIRSCHAUER (2003):

$$\boldsymbol{\alpha} = \mathbf{ln}\left(\frac{\sum_{\mathbf{t=1}}^{\mathbf{T}} \frac{\mathbf{w}_{\mathbf{ha}_{\mathbf{t}}}}{\mathbf{w}_{\mathbf{ha}_{\mathbf{t-1}}}}}{\mathbf{n-1}}\right) \tag{46}$$

where w_{ha} are the net incremental benefits per ha and year from the innovation in wheat production in Germany at time t.

The following flow chart (*Figure 9*) visualizes the previous explain model calculation for the different scenarios.

Figure 9: Model calculation



Note: x: scenario specific scenario; I^*_x: MISTICs; $\frac{\beta_x - 1}{\beta_x}$: hurdle rate; W_{T_x}: social reversible net benefits; J_{T_x}: Social irreversible benefits; w_{ha_x}: annual incremental irreversible benefits; j_{ha_x}:social incremental annual irreversible benefits per ha; θ: adoption rate; r: risk free rate of return; δ: convenience yield; σ: volatility of W_T.

Source: Authors' own compilation

Data

For the economic impact assessment, we compare HOSUT wheat with conventional wheat production for the years 2006 to 2013. Our main assumption is that HOSUT wheat will have 28%

higher yields compare to conventional wheat lines. The value corresponds to an average value found by SAALBACH et al. (2014), who compared HOSUT wheat lines with their conventional counterpart (Certo wheat lines) in micro-plot under field-like conditions in semi-controlled glass houses from the years 2009, 2010, and 2011. In this study we do not consider any potential market effects from the introduction of HOSUT wheat on the global wheat market. With the introduction of a GM based yield increasing innovation markets are likely to be affected by increasing quantity but also by potential trading restrictions or segregation costs or non-GM premiums. However, the prices effect will have complex reasons and any assumption about resulting price impacts would be vague, which justifies our simplifying assumptions.

Further, we do not consider a seed premium for HOSUT wheat for two reasons. First, seed premiums are very different between crop, GM traits and growing country (QAIM, 2009). Second, the technologies used to create HOSUT wheat lines were published and is not protected by a patent. Thus, any prediction of a seed premium would be inaccurate. Also due to this we ignore potential benefits to the seed developers.

For private reversible net benefits (W) we calculated gross margin per ha and in total for German wheat farmers with data for production costs, yields, and prices from the KTBL[25] (KTBL, 2004, KTBL, 2006, KTBL, 2008, KTBL, 2010, KTBL, 2012), BMELV[26] (BMELV, 2015), DESTATIS[27] (DESTATIS, 2016), and LFL[28] (LFL, 2015). Here we assumed a 5% decrease in price for HOSUT wheat lines due to lower relative protein content (SAALBACH et al., 2014). With that information we constructed wheat farmers' gross margin time series and determine their volatility.

In scenario II.II we considered nitrogen fixing for legumes (trefoil) with a value of 200kg/ha/a. The price for nitrogen is determine buy the price of urea with a nitrogen content of 44–46% (USDA, 2014b). Using the historical €/USD exchange rate (ECB, 2014) and assuming an average nitrogen content of 45% we calculated the price for pure N as fixed by legumes in €/ton. Based on that and considering the cost for N application (KTBL) we determined a legumes effect per ha (e.g. 10.28 €/ha in 2013). Prices, yield and scenario specific cost are summarized in *Table 20*.

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[25] Kuratorium für Technik und Bauwesen in der Landwirtschaft

[26] Federal Ministry of Food and Agriculture (Germany)

[27] Federal Statistical Office (Germany)

[28] Bavarian State Research Center for Agriculture

Table 20: Wheat prices, yields and production costs per ha

Year	Conv. wheat		Production cost (incl. cultivation and harvest costs in €/ha)			
	Price (€/t)	Yield	Conv. wheat	HOSUT wheat		
				Scen. I	Scen. II.I	Scen. II.II
2004	107.00	8.21	558.00	563.55	440.27	539.43
2005	96.00	7.51	597.71	609.22	475.95	570.55
2006	114.0	72.4	664.68	679.42	530.79	630.92
2007	179.0	6.99	681.85	698.41	545.63	644.45
2008	177.0	8.13	796.05	804.39	628.42	763.00
2009	123.0	7.84	875.10	886.83	692.83	824.96
2010	169.0	7.3	781.61	797.59	623.11	734.08
2011	215.0	7.06	848.74	866.25	676.75	786.59
2012	222.0	7.4	854.14	874.93	683.53	801.01
2013	206.0	8.03	863.40	875.52	684.00	808.35

Note: Authors' own calculation based on BMELV, DESTATIS, LFL, KTBL (see text)

As environmental impact and incremental irreversible non-private benefits (R) from the introduction of HOSUT wheat we consider saved CO_2 emissions due to decompensation zones in scenarios III and II.II. CO_2 emissions of 2.748 tCO_2/ha and of 0.7 tCO_2/ha for wheat and legumes cultivation, respectively, are derived using the ENZO2 Greenhouse Gas Calculator (IFEU, 2015). Further, we considered CO_2 emission from synthetic N production (ζ) with 5.88 $kgCO_2eq$/kgN (IFEU, 2015). CO_2 equivalent (χ) are economically evaluated with 65.18 €/tC following the literature review on social evaluation of carbon by TOL (2011). The results for R are presented in *Table 21*.

Table 21: Annual incremental irreversible non-private (non-farmer) benefits per ha

	Scen. II.I	Scen. II.II
In saved tCO_2/ha/a	0.39	0.24
In social €/ha/a	5.65	3.44

Source: Authors' own calculation based on ifeu (2015) and Tol (2011)

For the calculation of W and R we assume the total area allocated to wheat cultivation to stay constant at the average level from 2011–2013 (3 043 900 ha (DESTATIS, 2016)). The adoption of HOSUT wheat is assumed to follow the same pattern as for hybrid rape seeds in Germany for the period 1996–2012, which data are supplied by KLEFFMANN-GROUP (2012). For an accurate estimation of the adoption curve we must observe the actual situation. However, that is not possible in our case since neither HOSUT nor any other type of GM wheat ever got introduced to a commercial market before. To overcome this problem, we estimate the adoption function with data for the adoption of hybrid rapeseeds in Germany. Even though HOSUT wheat and hybrid rapeseeds differ due to their breeding technology and the crop species by using these data we can estimate an adoption function for a recent yield increasing innovation[29] for the German agricultural crop market.

The annual net benefits and cost from now until infinity are discounted using the risk-adjusted rate of return (μ), derived using the capital asset pricing model (CAPM). For CAPM we included a riskless rate of return of 3.37% as the average interest rate from 2006 to 2013 for German 30-year federal bonds (DEUTSCHE BUNDESBANK, 2014) and as a broad index, we used the average rate of return per ha for special crop farms in Germany from 2004 to 2013 (BMELV, 2015). The latter represents a diverse, risk reduced production or investment portfolio as opposed to broad index stocks, such as the S&P 500 or the DAX used in finance-based analysis. Eventually, all revenues and cost within the time series are deflated to the year 2013 (DESTATIS, 2014c).

Results and discussion

In scenario I we determined MISTICs for 2014 to be € 1 029 million or € 12.78 per citizen or € 338.06 per ha cultivated with wheat (*Table 22*). Thus, an immediate introduction of HOSUT wheat in Germany in 2014 would have been economical if its actual incremental social irreversible costs (I) did not exceed this value. MISTICs for the other scenarios (as shown in *Table 22*) can be interpreted similar. However, within the decompensation scenarios II.I and II.II parts of the HOSUT wheat's benefits are shifted towards the non-private part of society (J_T). The share of non-private benefits are 3.85% and 4.64% in scenario II.I and II.II, respectively.

Table 22: MISTICs for scenario I, II.I, and II.II

MISTICs in € (for 28% yield increasing wheat):	**Society**	**Per citizen**	**Per ha cultivated with wheat**	**Share of non-private benefits in %**
Scenario I	1029020955.85	12.78	338.06	0
Scenario II.I	623529014.32	7.75	204.85	3.85
Scenario II.II	653504506.83	8.12	214.69	4.64

Note: Maximum incremental social tolerable irreversible cost (MISTICs) for German society with a population of 80.5 million citizen (DESTATIS, 2014d), and wheat cultivation area of 3.04 mil ha (DESTATIS, 2016).
Source: Authors' own calculation

The results in *Table 22* are based on the hurdle rates 1.434, 1.029 and 1.053, for scenario I, II.I and II.I, respectively. A low hurdle rate indicates that an investment is more secure and thus it requires

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[29] Hybrid rapeseed were introduced to the German market in 1996

less insecure future return for being economical (*Equation 43*). The hurdle rate of 1.43 implies that, on average, every euro of social irreversible net cost needs to be matched by € 1.43 of social reversible net benefits to economical justify the authorization of HOUST lines.

Firstly, higher MISTICs in scenario I compared to scenario II.I and II.II are linked to the higher hurdle rate in scenario I. Secondly, however, also with a hurdle rate of one, and by that neglecting uncertainty and flexibility, total MISTICs of scenario I (€ 1 497 million) would be higher than in scenario II.I (€ 616 million) or scenario II (€ 656 million).

The quite low value of 3.85% and 4.64% as shares of non-private benefits in the scenarios II.I and II.II are due to quite low savings in N and CO_2 or their low monetary evaluation. This result indicates that HOSUT wheat, as a first generation GM crop, is mainly beneficial to farmers although a possible political regulation as decompensation zone would try to shift their benefits to the non-private society.

Throughout the calculation we assume a 28% yield increase based on trails under field-like trails in one location (Gatersleben, Germany). If HOSUT wheat would fails to increase yield by 28% but only 10%, MISTICs under scenario I would decrease to € 189 million in total and to € 2.35 per citizen. Such yield increases can be expected from the cultivation of wheat hybrids (LONGIN et al., 2013). Hybridisation is seen as a conventional breeding method and wheat hybrids are currently adopted by German farmers. Applying our line of argumentation with MISTICs, hybrid wheat is deregulated since society does not associate incremental irreversible costs above € 2.35 per citizen with this technology. However, as conventional breeding is not associated with irreversible cots any convention breeding innovation with positive MISTICs is likely to be deregulated.

All MISTICs values are derived with a risk adjusted rate of return (μ) of 17.6% and an adoption patter, which can be expressed with *Equation 31* as;

$$\theta(t) = \frac{0.84}{(1 + e^{-(-2.88+0.29t)})} \tag{47}$$

For the interpretation of the MISTICs values it important to consider that we did not account for any market price effect. Further, a yield increasing innovation, as HOSUT wheat will also contribute to social benefits in terms of food security, especially in developing countries. Since that aspect is beyond the scope of our analysis, the derived MISTICs are likely underestimate the situation.

Conclusion

In this study we determined MISTICs for a yield increasing (28%) innovation in wheat production for Germany. When a new technology is developed for practical agricultural application decision makers have the opportunity to ban (or postpone the decision) or authorize its market introduction. Those decisions include irreversibility and uncertainty of expected benefits and costs to society and the option to wait for more information. The option to deregulate the innovation should only be exercised if the benefit of an immediate release outweighs those of keeping the option and postponing the decision, should the option to release be exercised. The suggested RO model, MISTICs, can be used for a monetary evaluation of the situation and to structure the decision finding process. Within the MISTICs approach we accounted for private benefits to farmers, non-private benefits uncertainty, flexibility and an adoption process. Further, we constructed the theoretical decompensation scenarios II.I and II.II. Even though, the practical implementation of these scenarios is rather unlikely they showed how pure private benefits of high-yielding GM wheat might be transferred to society. But also within the decompensation scenarios our results indicate low potential gains for the non-private society–the society's majority. In combination with the general reluctant attitude towards GMOs by European (EUROPEAN COMMISSION, 2010a) or German (FORSA, 2014) societies that indicates low chances of an approval of GM wheat in Germany anytime soon.

With MISTICs we derive threshold values, limited to our assumptions, until which an immediate deregulation of GM HOSUT wheat will be social economical. The remaining challenge for decision-making bodies is to compare MISTICs with the actual irreversible costs (I) of GM HOSUT wheat. However, it might be unfeasible to produce a clear estimation for I with our current state of knowledge and it might even be zero. Eventually, since GM wheat seeds are not available in Germany one can conclude that currently society evaluates the potential irreversible costs of this technology to exceed MISTICs. But nevertheless, the option to deregulate HOSUT wheat will remain and decision can change with future information.

Empirical Study 5

Economic Evaluation of Yield-increasing Wheat Seeds Using a Distance Function Approach

The content of this empirical study is accepted for publication in a peer-reviewed journal
(Agricultural and Resource Economics Review).

Abstract

New wheat-breeding techniques, such as hybridization and genetic modification show increasing yield potential. This study involves estimating multi-output multi-input production technology by stochastic frontier techniques to evaluate the economic value of this yield potential. An input-oriented distance function is formulated and applied to European Farm Accountancy Data of 23 European countries. Based on the analysis, an average shadow value is derived for the increase in the marginal yield of wheat that corresponded to 18.87 €/ha. Further, technical change, technical efficiency, and returns to scale are measured for different European regions.

Keywords: shadow value, stochastic distance frontier, wheat production

JEL classification: Q12, Q18, D24

Introduction

Innovations in agricultural crop production contribute to food safety and food security and affect the environment. Recent innovations in plant breeding are often based on hybrid and genetic modification (GM) breeding strategies. These techniques are widespread in the global production of several cash crops such as corn, soybeans, rapeseeds, rice, and barley but not in the production of wheat. Simultaneously, the increase in wheat yield lags behind. For example, the annual average yield increase in rapeseeds in Europe from 1994 to 2014 corresponds to 3.6 percent, and it was more than double the yearly increase for wheat (1.6%) (FAOSTAT, 2016). However, wheat is one of the most important crops for global food security (Shiferaw, et al., 2013) and breeding innovations are crucial in keeping up with the increasing global demand. In addition to social relevance in terms of food security, wheat is also the most dominant crop for European farmers. Wheat is cultivated on approximately 26 percent of the 100.3 million ha of arable land in the EU-28 (FAOSTAT, 2016). Former studies indicated that wheat yield could be significantly increased by innovative breeding strategies. Based on GM technology, researchers developed a wheat variety (HOSUT) with a yield-increasing potential of 28 percent compared to its conventional counterpart when compared with its conventional counterpart (Saalbach, et al., 2014). Longin, et al. (2013) evaluated different hybrids and conventional wheat varieties and observed that hybrids were superior in terms of yield by 10.7 percent on average. Despite their potential, GM wheat varieties are not commercially produced due to social and political reasons, and hybrid wheat areas increase only gradually

In this study, we first apply stochastic frontier analysis and construct multi-output multi-input distance functions (DFs) to represent output-input relationships for European crop production technology. The estimated function provides empirical applications for measuring farm efficiency and productivity (Zhou, et al., 2014) and accounted for complementarity and supplementarity of inputs (Sauer and Wossink, 2013). Multi-output functions are beneficial because it is not necessary to distinguish as to which fraction of an input is used to produce a specific output. This type of detailed production information is often not available, as in the case of the European Farm Accountancy Data (FADN) used in this study. Further, using DFs has an advantage because it does not require price data or explicit behavioral assumptions (Kumbhakar, et al., 2015: 27). Second, based on the estimates for the multi-output multi-input production technology, a potential price is proposed in terms of a marginal shadow value (MSV) that farmers would be prepared to pay for yield-increasing wheat seed material. The MSV measures the economically justified costs for seeds that marginally increase yields and output in wheat production under the assumption of optimal input combination.

DFs constitute an established methodology to examine various agricultural production patterns. Studies including Brümmer, et al. (2002), Key and Sneeringer (2014), Newman and Matthews (2006), Reinhard, et al. (1999), Tsionas, et al. (2015), and Sauer and Latacz-Lohmann (2015) applied this methodology to analyze the European and American dairy farming sectors with respect to aspects such as technical efficiency and technical change. Other extant studies, such as Coelli and Fleming (2004), Fleming and Lien (2009), Paul and Nehring (2005), and Rahman (2009), studied farms' diversification strategies. Solís, et al. (2009), and Sauer and Wossink (2013) used this concept to analyze relationships between agricultural output and ecosystem services management of farms. Shadow prices derived from such agricultural DFs were mostly used to determine and value unwanted environmental damages (Färe, et al., 2006, Arandia and Aldanondo-Ochoa, 2011, Hailu and Veeman, 2001, Njuki and Bravo-Ureta, 2015). In contrast to these studies, the present study examines the shadow price of a yield-increasing innovation as a desirable outcome. To the best of our knowledge, no study to date has used DFs to construct a shadow price for such an (desirable) innovation. Previous studies, including Zilberman, et al. (2015), Brookes and Barfoot (2014) and Qaim (2009) which examined the economic benefits of breeding innovations, did not account for different production technologies and the substitutability of inputs.

The remainder of this paper is structured as follows. Section 2 introduces the theoretic model. Section 3 outlines the methodology used to construct DFs and measure marginal shadow values (MSVs). In Section 4, data and estimation procedures are described. Empirical results are presented in Section 5. The paper concludes with a summary and discussion of the main empirical findings and outlines the implications of the results.

Conceptual Framework

Production theory is the basis of the estimation of a stochastic frontier and input-output relationships in the present study. It is assumed that farms are offered a certain technology set that describes the relationship between inputs and outputs. The farmer can allocate inputs to generate outputs within the technology. Some inputs, such as land, could be exogenous in the short run, while others are endogenous. We assume that the farmer can choose inputs to optimize a cost-minimization objective function. Eventually optimizing behavior makes all input and output choices endogenous (Kumbhakar, et al., 2013). Endogenous decision variables imply the possibility of farms with inefficient production, which could then be measured by the DF approach. Furthermore, the setting of multi-output multi-input DFs allows to account for marginal interactive and substitutional relationships between inputs and outputs through elasticities.

Elasticities are estimated with respect to each input and output. A marginal shadow value for wheat seeds is derived through an economic evaluation of the marginal effects between the input (seed) and the output (wheat). This value is then used to evaluate the economic impact of marginal yield-increasing wheat seeds, which constitutes the main aim of the study. The MSV differs from market price because it evaluates the importance of the innovation within the production technology in monetary units while considering substitutional input relationships. Yield-increasing seeds are viewed as an embodied innovation, thereby implying that it is under the farmer's control to introduce the innovation and potentially extend her/his seed expenditures. The MSV indicates the maximum price premium for marginal yield-increasing seed innovations paid by the average farmer

In the model used in the study, input markets are seen as perfectly competitive. This implies that the size of a single farm relative to the size of the market is so small such that the farm has no influence on input prices.

This section involves the introduction of the theoretical framework of the DF upon which we base our marginal shadow-value calculation. The production technology set at time t, (S^t) represents an input vector $x^t = (x_1^t, \ldots, x_N^t) \in R_+^N$ that produces an output vector $y^t = (y_1^t, \ldots, y_M^t) \in R_+^M$, which is formally expressed as follows:

$$\mathrm{S}^t = \{(x^t, y^t) \colon x^t \; can \; produce \; y^t\} \tag{48}$$

(Newman and Matthews, 2006)

S^t denotes all feasible input–output vectors, and all inputs are assumed as freely disposable.

We apply an input oriented DF, developed by Shephard (1970), to represent multi-output and multi-input technologies. Given a technically feasible set (S^t), the input-oriented the DF measures for each observation the largest radial contraction of an input vector (x^t), given outputs (y^t) (Färe and Primont, 1995). The mathematical representation of the optimization function is as follows:

$$D_{\mathrm{I}}{}^t(x^t, y^t) = \max_{\rho}\{\rho > 0 \colon (x^t/\rho) \; \in \mathrm{S}^t)\} \tag{49}$$

This functional form measures the maximum scalar (denote as ρ), such that x^t/ρ remains in the feasible production technology set. The DF assumes values lesser than or equal to 1. That is $D_{\mathrm{I}}{}^t(x^t, y^t) \leq 1 \; if \; x^t \in \mathrm{S}^t$.

The DF value for a given observation corresponds to 1 if and only if the observation is part of the frontier of the production technology set S^t. Values between 0 and 1 indicate production with a distance to the production frontier and, thus, technical inefficiency (Coelli and Fleming, 2004). Increasing efficiency of a farm corresponds to a larger ρ value, which implies that the farm is closer to the stochastic frontier. By definition $D_{\mathrm{I}}{}^t(x^t, y^t)$ is a non-decreasing, positively linearly homogenous and concave in x^{t} and non-increasing in y^{t} (COELLI and FLEMING, 2004, SAUER et al., 2006).

Multi-output multi-input stochastic input-distance function approach

For the analysis in the study, an input-oriented DF was selected as we focus on marginal input effects. We estimate a multi-output multi-input distance DF in a flexible translog form allowing for all possible input-output interactions and including dummy variables for regions (denoted as (R)) and economic size (denoted as (E)):

$$\begin{aligned}\ln D_I^t(x,y,t) = {} & \alpha_0 + \sum_{m=1}^{M} \beta_{\mathrm{m}} lny_m^t + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{N} \beta_{\mathrm{mn}} lny_m^t lny_n^t + \sum_{k=1}^{K} \alpha_k lnx_k^t \\ & + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{L} \alpha_{\mathrm{kl}} lnx_k^t lnx_l^t + \sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{\mathrm{km}} lnx_k^t lny_m^t + \omega_0 t + \frac{1}{2}\omega_{00} t^2 \\ & + \sum_{m=1}^{M} \zeta_{\mathrm{mt}} lny_m^t t + \sum_{k=1}^{K} \eta_{\mathrm{kt}} lnx_k^t\, t + \sum_{p=1}^{P} \vartheta_{\mathrm{p}} Y_p + \sum_{q=1}^{Q} \iota_q C_q \\ & + \sum_{r=1}^{R} \kappa_r E_r \end{aligned} \tag{50}$$

D_I^t denotes the measured input distance function (IDF), where y and x correspond to vectors of outputs and inputs, respectively. The subscripts m and n denote farm output and the subscripts k and l denote farm inputs. All inputs and outputs include a time trend (t). Furthermore, α, β, δ, ω, ζ, η, ϑ, ι and K denote parameters to be estimated.

An input variable (in this case, seeds, as denoted by x_1^t) is used to normalize the stochastic IDF. This imposes linear homogeneity with respect to the inputs ($\sum_{k=1}^{K} a_k = 1$) (COELLI and PERELMAN, 1999). Additionally, for symmetry purposes the restriction $\alpha_{\mathrm{kl}} = \alpha_{\mathrm{lk}}$, $(k,l = 1,2,\dots,L)$ and $\beta_{\mathrm{mn}} = \beta_{\mathrm{nm}}$ $(m,n = 1,2,\dots,M)$ is fulfilled (COELLI and PERELMAN, 1999). Therefore, the DF can be rewritten to enable its econometric estimation as follows:

$$\begin{aligned}\ln\left(\frac{D_I^t}{x_1^t}\right) = {} & \alpha_0 + \sum_{m=1}^{M} \beta_{\mathrm{m}} lny_m^t + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{N} \beta_{\mathrm{mn}} lny_m^t lny_n^t + \sum_{k=2}^{K} \alpha_k ln\left(\frac{x_k^t}{x_1^t}\right) \\ & + \frac{1}{2}\sum_{k=2}^{K}\sum_{l=2}^{L} \alpha_{\mathrm{kl}} ln\left(\frac{x_k^t}{x_1^t}\right) ln\left(\frac{x_l^t}{x_1^t}\right) + \sum_{k=2}^{K}\sum_{m=1}^{M} \delta_{\mathrm{km}} ln\left(\frac{x_k^t}{x_1^t}\right) lny_m^t + \omega_0 t \\ & + \frac{1}{2}\omega_{00} t^2 + \sum_{m=1}^{M} \zeta_{\mathrm{mt}} lny_m^t t + \sum_{k=2}^{K} \eta_{\mathrm{kt}} ln\left(\frac{x_k^t}{x_1^t}\right) t + \sum_{p=1}^{P} \vartheta_{\mathrm{p}} R_p \\ & + \sum_{q=1}^{Q} \iota_q E_q = TL\left(y_m^t, \left(\frac{x_k^t}{x_1^t}\right), t\right) + \sum_{p=1}^{P} \vartheta_{\mathrm{p}} Y_p + \sum_{q=1}^{Q} \iota_q C_q + \sum_{r=1}^{R} \kappa_r E_r\end{aligned} \tag{51}$$

where TL denotes translog. The equation can be rearranged as follows:

$$lnD_I^t - lnx_1^t = TL\left(y_m^t, \left(\frac{x_k^t}{x_1^t}\right), t\right) + \sum_{p=1}^{P} \vartheta_{\mathrm{p}} Y_p + \sum_{q=1}^{Q} \iota_q C_q + \sum_{r=1}^{R} \kappa_r E_r \tag{52}$$

$$-lnx_1^t = TL\left(y_m^t, \left(\frac{x_k^t}{x_1^t}\right), t\right) + \sum_{p=1}^{P} \vartheta_{\mathrm{p}} Y_p + \sum_{q=1}^{Q} \iota_q C_q + \sum_{r=1}^{R} \kappa_r E_r - lnD_I^t \tag{53}$$

By setting $-lnD_{0i}^t = -u_i^t$ and including a symmetric error $\left(v_i^t\right)$ that reflects random factors, such as measurement errors, stochastic shocks, or unobserved inputs, the stochastic input DF (COELLI and PERELMAN, 1996) is obtained as follows:

$$-lnx_1^t = TL\left(y_m^t, \left(\frac{x_k^t}{x_1^t}\right), t\right) + \sum_{p=1}^{P} \vartheta_{\mathrm{p}} R_p + \sum_{q=1}^{Q} \iota_q E_q - u^t + v^t \tag{54}$$

where v_i^t denotes a random error term, which is assumed to be independent and identically distributed (i.i.d.) with $N(0, \sigma_v^2)$ and independent of u_i^t, and intended to capture events beyond the farmer's control. The term u_i corresponds to a non-negative random error term, which is assumed to be i.i.d. with $N(\mu, \sigma_u^2)$ and to follow the specification $u_i^t = u_i exp\big(-\eta(t-T)\big)$, that is intended to capture time-invariant technical inefficiency effects in inputs (REINHARD et al., 1999).

The first-order partial derivatives of *Equation 54* measure the partial elasticities for inputs x_k (ε_{x_1, x_k}) and the partial elasticity for outputs y_m (ε_{x_1, y_m}) relative to x_1. The value for ε_{x_1, y_m} $\left(-\varepsilon_{D^I, y_m} = -\frac{\partial lnD_i}{\partial lny_m} = \frac{\partial lnx_1}{\partial lny_m} = \varepsilon_{x_1, y_m}\right)$ estimates the required percentage change in x_1 from a 1 percent change in y_m, holding all output ratios constant (PAUL and NEHRING, 2005). The mean of the negative sums of the partial elasticities of y_m (ε_{x_1,y_m}) represents scale economies at the sample mean $\left(SE = -\sum_{m=1}^{M} \varepsilon_{x_1,y_m}\right)$ (PAUL and NEHRING, 2005). Thus, it reflects the extent to which overall input use must increase to support a 1 percent increase in all outputs by holding all input ratios constant. The elasticities of inputs $\left(\varepsilon_{x_1,x_k}\right)$ contain information on the slope of the production possibility frontier and represent the output contribution of x_k relative to x_1.

Further, for each subsample, technical change (TC), as the first-order partial derivative with respect to time (t) and technical efficiency (TE), are determined for each subsample. Given this, it is possible to differentiate various European production systems. The individual technical efficiency for the *i*th firm is then estimated as follows:

$$TE_i(u, x, t) = \exp(-u_i) = \frac{x_i^t}{x_i^{t*}} \tag{55}$$

where TE_i measures the deviation of particular observations from the estimated frontier (PAUL and NEHRING, 2005).

Marginal Shadow Value

The estimation of shadow prices is based upon the IDFs dual relationship with the cost function (FÄRE and PRIMONT, 2006). The partial elasticities, as mentioned previously, contain information on marginal products (MP) which are used to derive MSVs. In this study we are interested in the marginal shadow value for seeds as wheat output increases. Thus, we predominantly focus on the partial elasticity relationship ε_{x_1,y_m} with $x_1 = x_{seeds}$ and $y_m = y_{wheat}$;

$$\varepsilon_{x_1,y_m} = \frac{\partial ln x_1}{\partial ln y_m} \tag{56}$$

From the partial elasticity for output (or 'input share' of y_m [relative to x_1]) ε_{x_1,y_m}, we can calculate the marginal product ($\partial x_1 / \partial y_m$) of y_m on x_1, as follows:

$$\varepsilon_{x_1,y_m} = \frac{\partial ln x_1}{\partial ln y_m} = \frac{\partial x_1}{\partial y_m} \frac{y_m}{x_1} \tag{57}$$

$$MP_{x_1,y_m} = \frac{\partial x_1}{\partial y_m} = \frac{\varepsilon_{x_1,y_m} * x_1}{y_m} \tag{58}$$

In order to derive the MSV per ha, $MP_{x_1.y_m}$ is multiplied with the average total expenditures on seeds/ha ($E_{seeds} * ha^{-1}$) as given below:

$$MSV_{x_{seeds} \cdot y_m} = MP_{x_{seeds} \cdot y_m} * (E_{seeds} * ha^{-1}) \tag{59}$$

With respect to the model structure, the study follows KUMBHAKAR et al. (2015), assuming a half-normal distribution of the inefficiency term (u^t). Estimates of the parameters for the above-outlined model were obtained using maximum likelihood procedures based on a STATA 13 routine.

Data and estimation

Annual FADN data with 302,041 observations in 23 European countries (Belgium (BEL), Czech Republic (CZE), Denmark (DEN), Germany (DEU), Greece (ELL), Spain (ESP), Estonia (EST), France (FRA), Hungary (HUN), Ireland (IRE), Italy (ITA), Lithuania (LTU), Luxembourg (LUX), Latvia (LVA), Netherlands (NED), Austria (OST), Poland (POL), Portugal (POR), Finland (SUO), Sweden (SVE), Slovenia (SVN), Slovakia (SVK), and the United Kingdom (UKI)), from 2005 to 2012, are used for the analysis. The FADN data set consists of annual accountancy data from a sample of commercial agricultural holdings in the EU. The data were collected by the Member States of the EU by following a harmonized bookkeeping principle (EUROPEAN COMMISSION, 2016a).

Within the countries of the EU, the Common Agricultural Policy (CAP) sets common farming regulations, e.g., with respect to environmental standards and subsidy payments (decoupled direct payments). Nevertheless, crop production systems differ due to farm structures, traditional differences, and especially due to agroclimatic conditions. To account for these differences, four subsamples (*Table 23*) were formed based on agro-climatic zones proposed by BOUMA (2005). The subsamples North, East, South and West include the following different countries:

Table 23: Subsamples' composition

Subsample	Countries
North	SUO, SVE
East	EST, HUN, LTU, LVA, POL, SVN, SVK
South	ELL, ESP, ITA, POR
West	BEL, CZE, DAN, DEU, FRA, IRE,LUX, NED, OST, UKI

Source: Authors' own compilation

The farms in the samples produce a variety of outputs (i.e., crops, dairy, livestock) for which they rely on a variety of inputs. This study focuses on the characteristics of specialized crop-producing farms because these are most likely to engage in wheat production. Therefore, the farms selected from the sample include farms that generate at least 60 percent of their annual revenue by crop production in every year of observation. This results in an unbalanced panel based on a total of 73,719 observations after removing outliers from the sample. The farms remaining in the sample operated on an annual average area of 1,733,293 ha, which is approximately equal to 1.6 percent of European crop land (EUROSTAT, 2016a). The average farm size in the sample is 186.5 ha, of which 70 ha on average were cultivated with wheat. The largest farms in the sample are in the Eastern region, where the average farm size is 230 ha.

The model estimation included specifying inputs and outputs based upon the production process of wheat farms. Two output variables are selected, namely total production of common wheat (y_1^t) and total production of other field crops (y_2^t), which accounts for all produced crops except wheat. Furthermore, five input variables were included, namely seed and plants (x_1^t), fertilizers (x_2^t), crop protection (x_3^t), machinery (x_4^t), labor (x_4^t) and total crop area (x_5^t). The variables measured in monetary terms (€) refer to total production value (y_1^t, y_2^t) and input expenditures (x_1^t, x_2^t, x_3^t). All data measured in EUR were deflated using real agricultural price indices with the base year 2005 provided by the Eurostat database (EUROSTAT, 2016b).

The analysis is conducted with the entire sample as well as separately for the four subsamples (production regions North, East, South, and West). The descriptive statistics for the entire sample are reported in *Table 24*.

Table 24: Descriptive Statistics of the Sample Variables (aggregated sample)

Variables (Obs: 75,784)	**Unit**	**Mean**	**Min.**	**Max.**	**Std. Dev.**
Outputs					
Common wheat total production	EUR	64,584.7	173.3	5,872,466	143,783.1
Other field crops total production	EUR	111,459.5	146	9,589,848	249,319.8
Inputs					
Total crops area	hectare	186.5	2.2	7,310	367.2
Seed and plants	EUR	13,175.2	0	1,118,402	32,801.5
Fertilizers	EUR	27,977.7	0	2,004,995	58,648.2
Crop protection	EUR	19,953.1	0	1,548,833	44,025.3
Machinery	EUR	127,965.1	0	11,394,706	254,748.4
Labor	hours	6,399.2	16	524,505	16,268

Note: All monetary values are adjusted for inflation using the price indices for agricultural outputs and inputs with base year 2005 based on EUROSTAT (2016b)

Source: Authors' own calculation

From 2005 to 2012, the average total crops area per year in the sample remains almost constant in the range of 183–197 ha, and the average yearly wheat cultivation area ranges between 66 ha and 73 ha. Simultaneously, the total output of wheat varies between 571 €/ha and 1,256 €/ha and indicates an upward trend over time. Expenditures for seeds and plants increased from 64 €/ha to 85 €/ha, while labor on average, remained constant between 6,290 h and 6,991 h.

The included dummy variables to account for year (Y), country (C) and economic size (E) are defined according to the FADN. It is assumed that C picks up country differences in production systems, subsidy payments, and environmental conditions within a country. These regions are usually identical to political boarders, e.g. the regions within Germany correspond with the German federal states. With respect to E, the FADN defines 14 different classes according to the standard output of farms (EUROPEAN COMMISSION, 2016a).

Different observations in the data set show 0 values for individual variables, which cannot be handled by the logarithmic functional specification. We follow the procedure outlines by RASMUSSEN (2010) and deleted those observations (a total of 2287 observations were deleted). Only 3 percent of the sample was affected by this, and thus a significant bias is not expected with respect to the results.

In the empirical application of production or distance functions on agricultural holdings endogeneity is a general concern as discussed by, e.g., KUMBHAKAR (2001), KUMBHAKAR (2011), BRÜMMER et al. (2002), SAUER and LATACZ-LOHMANN (2015), and SOLÍS et al. (2009). Endogeneity problems occur in an IDF if outputs are not exogenously given. This problem occurs in agricultural crop production to a certain extent, because they are partly the result of exogenous climate factors and endogenous farming decisions. The endogeneity impact of outputs on the next season's inputs is less problematic in developed countries compared to developing countries where a bad harvest strongly influences the possibility to invest in next season's inputs. Farms in developed countries mostly follow a standard cultivation pattern that is far less influenced by the previous harvest outcome. Compared to multi-output production functions, DFs are superior in avoiding such endogeneity problems, although they fail avoiding them completely (KUMBHAKAR, 2011). Because the inputs on the right-hand side of *Equation 51* appear as ratios, they are likely to suffer less from endogeneity (BRÜMMER et al., 2002). Additionally, outputs are assumed to be exogenous to the farm's input choice to the extent that farms are cost minimizers, and panel data estimators control for farmers' input adjustment due to unobserved time-invariant conditions (SAUER and WOSSINK, 2013).

Empirical Results and Discussion

This section presents the results for first-order elasticities, marginal shadow values, scale economies, technical efficiency, and technical change. Detailed estimates for the parameters of the IDF based on aggregated data for 23 European countries[30] are presented in *Table 26* (*Appendix Empirical Study 5*). In the estimation for the entire sample, we find more than 90 percent of the parameters to be statistically significant different from zero at least at the 5 percent level. Particularly, first-order coefficients and the dummy variables Y, C and E are mostly significant. A number of coefficients for the interaction variables (second order terms) are also significantly different from zero. This indicates non-linearities in the production structure and therefore supports the application of a flexible translog specification (RAHMAN, 2009).

Applying the delta method, we derive the partial first-order elasticities of the translog function at the sample means for the entire EU region and the four subsamples as reported in *Table 25*. Furthermore, *Table 25* reports the estimate of the MSV, SE, TE, and TC evaluated at the sample means.

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[30] Results for single European countries are available from the author on request.

Table 25: Elasticities MSV, SE, TE, and TC (evaluated at the sample means)

Region		**EU**	**North**	**East**	**South**	**West**
Obs.		73,719	1,626	29,527	8,670	33,896
Elasticities of outputs						
$\boldsymbol{\varepsilon_{x_1,y_1}}$ **(wheat)**		−0.24430	−0.21755	−0.19222	−0.21269	−0.26205
$\boldsymbol{\varepsilon_{x_1,y_2}}$ **(other crops)**		−0.30705	−0.24065	−0.26673	−0.29854	−0.29692
Elasticities of inputs						
$\boldsymbol{\varepsilon_{x_1,x_2}}$ **(fertilizer)**		0.07202	0.08624	0.07492	0.06833	0.07217
$\boldsymbol{\varepsilon_{x_1,x_3}}$ **(crop protection)**		0.17717	0.12236	0.11490	0.12787	0.22985
$\boldsymbol{\varepsilon_{x_1,x_4}}$ **(machinery)**		0.04143	0.03060	0.04458	0.02871	0.03592
$\boldsymbol{\varepsilon_{x_1,x_5}}$ **(labor)**		0.26246	0.21145	0.26812	0.31773	0.25176
$\boldsymbol{\varepsilon_{x_1,x_6}}$ **(total crop area)**		0.30212	0.42679	0.37014	0.29511	0.26125
MSV (yield-increasing wheat seeds in €	farm total	1,303.46	838.90	916.58	635.95	1500.70
	per ha	18.87	17.97	12.79	31.85	15.60
SE ($\boldsymbol{\varepsilon_{x_1,y}}$**)**		0.52030	0.45819	0.45895	0.51123	0.55897
TE (within the subsample)		0.91203	0.90680	0.91561	0.88820	0.98908
TC		–0.291%	–0.09%	0.23%	–0.25%	–0.192%

Note: Marginal shadow value (MSV), scale economies (SE), technical efficiency (TE), technical change (TC) *Source: Authors' own calculation*

The first-order derivatives or partial elasticities reflect input substitutability with respect to seeds (ε_{x_1,x_k}) and marginal output contributions (ε_{x_1,y_m}). As the dependent variable in *Equation 54* is $-lnx_1$, these estimates show negative signs for partial derivatives with respect to outputs and positive signs for partial derivatives with respect to inputs. The positive signs of all elasticities for the inputs imply their substitutability with total seed expenditures $\left(\frac{\partial lnx_1}{\partial lnx_k} < 0\right)$. The negative signs of all elasticities for the outputs imply that a reduction in total seed expenditures (x_1) is positively associated with a reduction in outputs $\left(\frac{\partial lnx_1}{\partial lny_m} > 0\right)$ (Rahman, 2009). Thus, the estimations confirm the monotonicity conditions for the specified stochastic input-oriented distance frontier at the sample means (Rasmussen, 2010). The (input) elasticities for outputs (ε_{x_1,y_m}) represent the percentage in x_1 associated with a 1 percent change in y_m, holding all input ratios $\left(ln\left(\frac{x_k}{x_1}\right)\right)$ constant. Because x_1 corresponds to the relative measure for the inputs, all other inputs need to change similar to x_1 in order to hold the input ratios constant. Thus, ε_{x_1,y_m} summarizes the (total) input expansion required for a 1 percent increase in y_m and can be considered an input share of y_m (relative to x_1) (Paul and Nehring, 2005). For example, the elasticity of −0. 0.24430 for wheat output

$\left(\varepsilon_{x_1,y_1}\right)$ implies that a 1 percent increase in wheat production is associated with a 0. 24430 percent increase in (all) inputs, measured at the sample mean and holding all input ratios constant.

In a manner similar to ε_{x_1,y_m}, the elasticities for the inputs $\left(\varepsilon_{x_1.x_k}\right)$ represent the percentage change of x_1 associated with a 1 percent change in x_k. However, in an IDF (*Equation 54*) x_k is measured relative to x_1. For example, the elasticity value of 0.30212 for the input land $\left(\varepsilon_{x_1,x_6}\right)$ implies that a 1 percent decrease in the ratio of land (x_6) to seeds (x_1), due to a change in x_6, could be substituted by 0.30212 percent increase in all inputs. Again, this change, which would keep production constant, is measured at the sample means.

For every subsample, ε_{x_1,y_2} is found to exceed ε_{x_1,y_1}, which confirms that the production of y_2 (crops other than wheat) requires a higher input share for farms at the sample means. The estimates for the partial elasticities of inputs ($\varepsilon_{x_1.x_k}$) represent their proportional marginal productivity. The variables land ($\varepsilon_{x_1.x_5}$) and labor ($\varepsilon_{x_1.x_6}$) show the largest magnitudes, and this suggests that these are the inputs with the highest contribution to outputs within the estimated models.

Technical efficiency and technical change

The results indicated that technical efficiency (TE) remains fairly constant over time and varies between 0.896 and 0.925 at the aggregated EU level. The estimates exceed that in a previous study of the TE of European crop farmers by RASMUSSEN (2010) where a value of 0.82 was determined based on data from 1985 to 2006. However, PAUL and NEHRING (2005) determine a higher TE of crop farms in the U.S. corn belt of 0.94 from 1996 to 2000. It is important to note that TE is only measured within each subsample and only comparable to a limited extent between different subsamples.

The rate of technical change (TC) can be calculated using the derivative of the DF (in logs) with respect to time $\left(\varepsilon_{D_i,t} = \frac{\partial lnD_i}{\partial t}\right)$ (KUMBHAKAR et al., 2013). We determine an average annual TC of −0.291 percent, thereby implying a negative technical change over time, albeit at a relatively low rate. In contrast, SAUER and LATACZ-LOHMANN (2015) analyzed German dairy farms from 1996–2010 and found a positive average annual technical change of 1.5 percent.

Scale economies

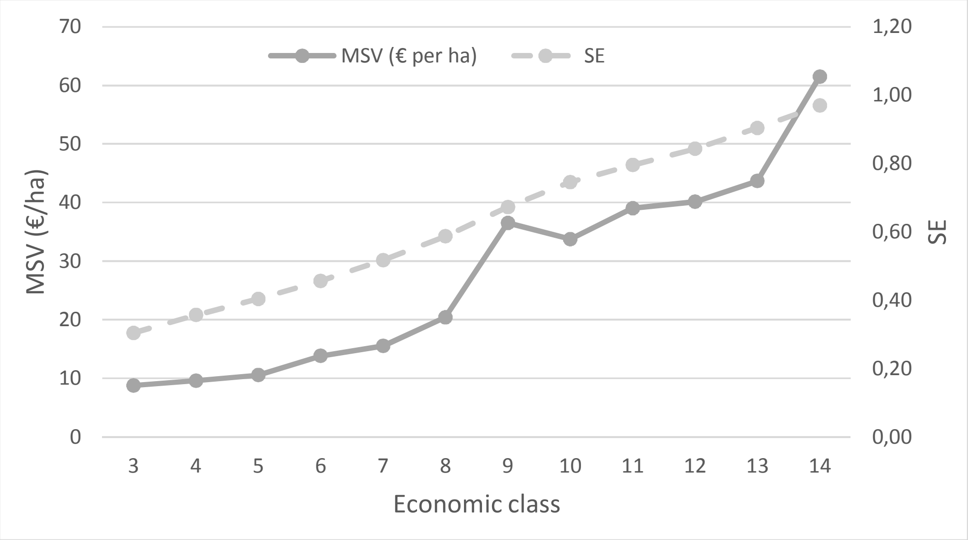
The negative sum of elasticities of outputs (ε_{x_1,y_m}) represents scale economies (SE) at the sample means. Thus, it reflects the extent to which overall input use must increase to support a 1 percent increase in all outputs (PAUL and NEHRING, 2005). Values below 1 imply that the production possibility frontier expands more than proportionally with an increase in resources, which indicates increasing returns to scale. Accordingly, an SE value of 0.5203 (*Table 25*) indicates that a 0.5203 percent increase in all inputs is required to sustain a 1 percent increase in outputs. Thus, on average, European crop farmers are likely to benefit from economies of scale. *Figure 10* shows increasing SE with increasing economic size, which indicates that farms in higher economic classes are closer to the optimal farm size. We derive low SE values at the sample mean similar to previous European farms studies including PAUL and NEHRING (2005) (SE value of 0.654) and FLEMING and LIEN (2009) (SE value of 0.700).

The analysis provides detailed insight into the European crop production system. However, due to data aggregation and availability, it is not possible to check specifically for farm individual aspects, such as soil quality or farmers' characteristics. For example, SAUER and LATACZ-LOHMANN (2015) show in their DF model that the farmers' age and education level affect efficiency and investment in innovations.

Marginal shadow value (MSV)

We estimate an average MSV for yield-increasing seed material of 18.87 €/ha for the average European crop farm. Depending on the region, this value varies between 15.60 €/ha and 31.85 €/ha (*Table 23*). The reason for these differences is not easy to identify but can rather be considered a result of complex differences in regional crop production systems and technologies influenced by factors such as climate conditions, farm structure, and land and labor availability. Further, because the MSV measures a percentage increase of absolute terms, one can expect a region with generally lower revenue/ha— e.g. the North and East regions— to show a lower MSV/ha. Within the total sample, identify increasing average MSVs with an increase in economic class (*Figure 10*). Consequently, farmers in a higher economic class could pay a higher price for yield-increasing seeds.

Figure 10: Average MSV and SE relative to Economic Class



Note: Marginal shadow value (MSV), scale economies (SE)
Source: Authors' own compilation

Incremental revenue from a 1 percent yield increase in wheat are, on average, 92.9 €/ha for EU crop farms. The MSV for the input seed is 20.3 percent of this value. The result is consistent with production theory because the incremental use of different substitutable inputs could lead to a yield increase. Elasticities indicate the marginal output effect for individual inputs. Thus, the MSV for one specific input must always be smaller than the incremental revenue due to substitutability.

Robustness

Various specifications of the model were compared based on likelihood ratio tests, for which the results are presented in *Table 27* (*Appendix Empirical Study 5*). We tested for systematic differences between the model with different subgroups (specialized crop farms and general farms), with and without dummy variables (year, country, and economics size), and with and without a time variable to include technical change. The test results support the sampling decision at statistically significant levels. Further, we find the chosen translog functional form superior to a Cobb-Douglas functional form. The hypothesis of no inefficiencies in the model was rejected at least at a 10 percent level for all four sub groups. This indicates that the applied Maximum Likelihood based estimation is more suitable than an Ordinary Least Square regression model.

Conclusions

In the preceding analysis, we estimate translog IDFs for a comprehensive unbalanced panel of European farms (FADN data) for the period from 2005 to 2012. We evaluate a range of measures capturing the output-input relationships for European crop farms. Additionally, we exploited the duality between the IDF and the cost function to derive MSV of marginal yield-increasing breeding innovations in wheat for four European crop production regions. On average, the derived a MSV of 18.87 €/ha for European crop farms. However, farm individual shadow prices will differ from that value due to general differences in regions, economic classes and SE.

Our findings give valuable information to farmers, seed producers, and other political stakeholders. The derived MSVs indicate the marginal economic value of breeding innovations. Those breeding innovation's benefits are usually shared between the seed developer, the farmer, and to a lower extent the consumer, but the percentage distribution of the shares can be very different based on the region and trait (QAIM, 2009). In our model, the MSVs for seeds indicate the economic value of crop improvements to farms. However, through seed prices or breeding premiums, innovation's benefits are shared between the seed developer and the farmer. Furthermore, yield increases provide social benefits in terms of food security and offer potential benefits for environmental conservation and resource savings. MSVs give theoretical values for breeding innovations; however, the actual values are also determined by practical circumstances, such as laws and agreements. The International Union for the Protection of New Varieties of Plants (UPOV) aims to protect breeding innovations for the benefit of society through the application of an effective regulatory system. Not all countries in our sample signed the latest UPOV act.[31] In a weak regulatory system, MSV and long-term benefits of breeding innovations might be lost.

Generally, the results of the present study are independent from any breeding techniques such as conventional, hybrid, and GM. The suggested MSV approach can also be applied to economically evaluate marginal improvements in other production factors.

Appendix

Table 26: *Estimation Results: Multi-output Multi-input Stochastic IDF for All European Countries*

Total crops area	**Parameters**	**Coeff.**	**Std. Err.**	**P>|z|**
Frontier				
ln(wheat)	β_1	0.1854413		0.000
ln(other crops)	β_2	0.0542069		0.000
ln(wheat) x ln(wheat)	β_{11}	–0.1211454		0.000
ln(wheat) x ln(other crops)	β_{12}	0.057113		0.000
ln(other crops) x ln(other crops)	β_{22}	–0.115165		0.000
ln(wheat) x ln(fertilizer)	δ_{12}	0.0212942		0.000
ln(wheat) x ln(crop protection)	δ_{13}	–0.0126239		0.000
ln(wheat) x ln(machinery)	δ_{14}	0.0077065		0.000
ln(wheat) x ln(labor)	δ_{15}	–0.0524704		0.000
ln(wheat) x ln(land)	δ_{16}	0.0599189		0.000
ln(other crops) x ln(fertilizer)	δ_{22}	0.0025249		0.716
ln(other crops) x ln(crop protection)	δ_{23}	0.0184444		0.000
ln(other crops) x ln(machinery)	δ_{24}	0.0108085		0.000
ln(other crops) x ln(labor)	δ_{25}	0.0125612		0.000
ln(other crops) x ln(land)	δ_{26}	–0.0615178		0.000
ln(fertilizer)	α_2	–0.1002692		0.000
ln(crop protection)	α_3	0.1807334		0.000
ln(machinery)	α_4	–0.1360751		0.000
ln(labor)	α_5	0.3568976		0.000

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[31] Luxembourg and Greece have not signed any form of UPOV, Belgium is still under the 1972 act, and Portugal is under the 1978 act.

ln(land)	α_{6}	0.2852327	0.000
ln(fertilizer) x ln(fertilizer)	α_{22}	0.044459	0.000
ln(fertilizer) x ln(crop protection)	α_{23}	–0.0326878	0.000
ln(fertilizer) x ln(machinery)	α_{24}	–0.0103323	0.000
ln(fertilizer) x ln(labor)	α_{25}	0.0056864	0.053
ln(fertilizer) x ln(land)	α_{26}	0.0114391	0.050
ln(crop protection) x ln(crop protection)	α_{33}	0.0814748	0.000
ln(crop protection) x ln(machinery)	α_{34}	–0.007717	0.000
ln(crop protection) x ln(labor)	α_{35}	–0.0050478	0.305
ln(crop protection) x ln(land)	α_{36}	–0.0137855	0.000
ln(machinery) x ln(machinery)	α_{55}	0.0160653	0.000
ln(machinery) x ln(labor)	α_{56}	0.0098117	0.000
ln(machinery) x ln(land)	α_{57}	0.006551	0.000
ln(labor) x ln(labor)	α_{66}	0.0176325	0.000
ln(labor) x ln(land)	α_{67}	0.0161114	0.000
ln(land) x ln(land)	α_{77}	–0.0263266	0.000
t	ω_{0}	–0.7897497	0.894
t^{2}	ω_{00}	0.107003	0.001
ln(wheat)_t	ζ_{1t}	0.0060681	0.000
ln(other crops)_t	ζ_{1t}	–0.0075074	0.000
ln(fertilizer)_t	η_{2t}	0.0059123	0.000
ln(crop protection)_t	η_{3t}	–0.0018287	0.177
ln(machinery)_t	η_{4t}	0.0006367	0.040
ln(labor)_t	η_{5t}	–0.000369	0.720
ln(land)_t	η_{6t}	–0.000712	0.687
year_dummy2005		–2.150663	0.000
year_dummy2006		–1.540443	0.000
year_dummy2007		–1.081107	0.000
year_dummy2008		–0.6909532	0.000
year_dummy2009		–0.2313109	0.000
year_dummy2010		0 (omitted)	
year_dummy2011		0 (omitted)	
year_dummy2012		0 (omitted)	
country_dummyBEL		0.1588165	0.000
country_dummyCZE		–0.313934	0.000
country_dummyDAN		0.2093997	0.000
country_dummyDEU		0.0316546	0.000
country_dummyELL		–0.0281328	0.009
country_dummyESP		–0.0404519	0.000
country_dummyEST		–0.4865652	0.000
country_dummyFRA		0.0165101	0.000
country_dummyHUN		–0.260656	0.000

country_dummyIRE		–0.056374	0.002
country_dummyITA		0.1217846	0.000
country_dummyLTU		–0.3860692	0.000
country_dummyLUX		–0.1585622	0.000
country_dummyLVA		–0.4901362	0.000
country_dummyNED		0.1818278	0.000
country_dummyOST		0.0427528	0.000
country_dummyPOL		–0.2660551	0.000
country_dummyPOR		–0.3094652	0.000
country_dummySUO		–0.1657136	0.455
country_dummySVE		–0.1657136	0.000
country_dummySVK		–0.4963437	0.000
country_dummySVN		–0.0714956	0.000
country_dummyUKI		0 (omitted)	
EcoSize_dummy1		1.477931	0.000
EcoSize_dummy2		1.289724	0.000
EcoSize_dummy3		1.122759	0.000
EcoSize_dummy4		0.9272114	0.000
EcoSize_dummy5		0.7325038	0.000
EcoSize_dummy6		0.5290397	0.000
EcoSize_dummy7		0.3269214	0.000
EcoSize_dummy8		0.1816877	0.000
EcoSize_dummy9		0.0856994	0.000
EcoSize_dummy10		0.0525546	0.004
EcoSize_dummy11		–0.0175358	0.310
EcoSize_dummy12		0 (omitted)	
Constant	α_0	–2.049934	0.000
Usigmas			
t		–0.0996319	0.001
Constant		–3.800857	0.000
vsigmas			
Constant		–3.095368	0.000

Log likelihood: 5510.9927

Number of observation: 73719

Wald chi2 (77): 2280896.20

Prob > chi2: 0.0000

Note: The dummy variables year_dummyXXXX, country_dummyXXX and EcoSize_dummyXX control for different years, countries and economic sizes in the sample, respectively. The economic size classes are defined according to the FADN. The coefficient cannot be interpreted directly. Using the delta method relevant coefficients are presented in *Table 25* *Source: Authors' own calculation*

Table 27: Log likelihood test ratios *Source: Authors' own calculation*

Test	Hypothesis	Region			
		North	**East**	**South**	**West**
Sub-samples	H_0: Specialized and non- specialized farms share the same technology H_A: Specialized and non- specialized farms have different technology	Test-Statistic: 479.74 Critical value: $\chi^2_{62.\ 0.01}$=90.80 Rejected at 0.01% significance	Test-Statistic: 1373.00 Critical value: $\chi^2_{70.\ 0.01}$=100.43 Rejected at 0.01% significance	Test-Statistic: 363.28 Critical value: $\chi^2_{67.\ 0.01}$=96.82 Rejected at 0.01% significance	Test-Statistic: 11221.92 Critical value: $\chi^2_{68.\ 0.01}$= 131.14 Rejected at 0.01% significance
Dummy variables (country)	H_0: Including country dummy variables does not improve the model fitness H_A: Including country dummy variables does not improve the model fitness	Test-Statistic: 130.88 Critical value: $\chi^2_{1.\ 0.01}$=6.63 Rejected at 0.01% significance	Test-Statistic: 2026.82 Critical value: $\chi^2_{6.\ 0.01}$=16.81 Rejected at 0.01% significance	Test-Statistic: 484.19 Critical value: $\chi^2_{3.\ 0.01}$=11.34 Rejected at 0.01% significance	Test-Statistic: 1750.08 Critical value: $\chi^2_{9.\ 0.01}$=21.67 Rejected at 0.01% significance
Dummy variables (economic size)	H_0: Including economic size dummy variables does not improve the model fitness H_A: Including economic size dummy variables does not improve the model fitness	Test-Statistic: 336.64 Critical value: $\chi^2_{8.\ 0.01}$=20.09 Rejected at 0.01% significance	Test-Statistic: 10279.32 Critical value: $\chi^2_{11.\ 0.01}$=24.72 Rejected at 0.01% significance	Test-Statistic: 1482.25 Critical value: $\chi^2_{11.\ 0.01}$=24.72 Rejected at 0.01% significance	Test-Statistic: 5694.92 Critical vvalue: $\chi^2_{10.\ 0.01}$=23.21 Rejected at 0.01% significance
Dummy variables (year)	H_0: Including year dummy variables does not improve the model fitness H_A: Including year dummy variables does improve the model fitness	Test-Statistic: 120.43 Critical value: $\chi^2_{5.\ 0.01}$=15.09 Rejected at 0.01% significance	Test-Statistic: 1919.40 Critical value: $\chi^2_{5.\ 0.01}$=15.09 Rejected at 0.01% significance	Test-Statistic: 360.92 Critical value: $\chi^2_{5.\ 0.01}$=15.09 Rejected at 0.01% significance	Test-Statistic: 1277.45 Critical value: $\chi^2_{5.\ 0.01}$=15.09 Rejected at 0.01% significance
Time variable	H_0: Including a time variable does not improve the model fitness H_A: Including a time variable does improve the model fitness	Test-Statistic: 43.51 Critical value: $\chi^2_{8.\ 0.01}$=20.09 Rejected at 0.01% significance	Test-Statistic: 272.39 Critical value: $\chi^2_{7.\ 0.01}$=18.48 Rejected at 0.01% significance	Test-Statistic: 93.10 Critical value: $\chi^2_{7.\ 0.01}$=18.48 Rejected at 0.01% significance	Test-Statistic: 202.30 Critical value: $\chi^2_{7.\ 0.01}$=18.48 Rejected at 0.01% significance
Cobb-Douglas functional type	H_0: Cobb-Douglas functional type H_A: Translog DF	Test-Statistic: 188.34 Critical value: $\chi^2_{28.\ 0.01}$=48.28 Rejected at 0.01% significance	Test-Statistic: 4028.13 Critical value: $\chi^2_{28.\ 0.01}$=48.28 Rejected at 0.01% significance	Test-Statistic: 1487.04 Critical value: $\chi^2_{28.\ 0.01}$=48.28 Rejected at 0.01% significance	Test-Statistic: 2021.14 Critical value: $\chi^2_{28.\ 0.01}$=48.28 Rejected at 0.01% significance

Inefficiency (critical χ^2 values according to (Kodde and Palm, 1986)	H_0: No technical inefficiency present H_A: Technical inefficiency present	Test-Statistic: 2.41 Critical Value: Mixed $\chi^2_{1.\ 0.01}$=5.412 Rejected at 0.01% significance	Test-Statistic: 21.90 Critical Value: Mixed $\chi^2_{1.\ 0.01}$=5.412 Rejected at 0.01% significance	Test-Statistic: 8.03 Critical Value: Mixed $\chi^2_{1.\ 0.01}$=5.412 Rejected at 0.01% significance	Test-Statistic: 9818.42 Critical Value: Mixed $\chi^2_{1.\ 0.01}$=5.412 Rejected at 0.01% significance

5 General Discussion

In the introduction of this dissertation the necessity for agricultural innovations is pointed out. In this respect, GM plant breeding is presented as an opportunity. GM crops offer different characteristics and possible applications (generation I, II, III). Benefits and costs linked to these technologies can affect seed developers, farmers, environments, and consumer differently. Similar to other innovations, long term effects from GM crops are not known yet and difficult to predict. Especially long term social irreversible costs due to environmental and consumers' health hazards are seen as potential threats of GM crops. Many societies evaluate such perceived risks or costs higher than potential benefits. In Europe, this has result in political deadlock regarding approval of cultivation of new GM crops.

The overall research aim of this dissertation is to provide empirical analyses of socio-economic consequences and potential of GM crop technology applications. The previous empirical studies contribute to existing literature which evaluates the socio-economic aspects of GM crops under different perspectives.

The conducted empirical studies analyze empirical situations of unintended appearances of selected GM seeds (*Empirical Studies 1* and *2*) and the socio-economic potential of selected GM breeding innovations for Germany and Europe (*Empirical Studies 3, 4*, and *5*). In accordance with the specific research question appropriate methodologies are applied. The main empirical findings from the different perspectives are summarized in *Table 28*.

Table 28: Main findings in the Empirical Study 1, 2, 3, 4, and 5

Empirical Study	**Main empirical findings**
1	The EU's current regulation of a zero threshold for unapproved GMO events in seeds can result in legal insecurity and bears regulatory challenges.
2	International wheat markets lost usual cointegration relationships after appearance of unauthorized GM wheat in the U.S. and an ensuing import ban by Japan and the Republic of Korea during June and July 2013.
3	MISTICs for GM HR rape seeds in Germany are estimated to be €13.8 and €7.28 per citizen, with and w/o a 10% yield increase, respectively. Even though GM HR rape seeds are currently banned, the option to introduce the technology at some future point in time remains. This option value is evaluated with €249.058 million.
4	MISTICs for GM yield-increasing wheat in Germany are estimated to be between €7.75 and €12.78 per citizen, with and w/o a decompensation scenario, respectively. A decompensation scenario is used as a theoretical concept to transfer private (farm) to non-private (social) benefits.
5	Multi-output multi-input distance functions are applied to derive an average marginal shadow value (MSV) for yield-increasing wheat seeds of 18.87 €/ha for European crop farms. MSVs will differ for European crop farms due to general production differences in regions and economic classes.

Note: Maximum incremental social tolerable irreversible costs (MISTICs) identify an upper bound associated for incremental irreversible costs, up to which the release of a new technology can be considered socio-economical.

Source: Authors' own compilation

In the *Empirical Study 1*, a case study about unintended appearances of GM maize and GM potatoes in Germany in 2010 is conducted. The Lower Saxony State Office for Consumer Protection and Food Safety found traces of GMOs in various seed lots of Pioneer's maize variety PR38H20. Farmers that planted those seeds were committed to destroy their maize crops. Based on the empirical case we concluded legal insecurity and regulatory challenges in handling GM contaminated seed material.

In the *Empirical Study 2*, we showed that international wheat markets lost usual cointegration relationships after appearance of unauthorized GM wheat in the U.S. and an ensuing import ban by

Japan and the Republic of Korea during June and July 2013. Both importing countries have a rejective attitude towards GMOs in wheat. The global market turbulences, found in the investigated case, indicate the limited economic potential of some GM crops due to individual countries' preferences.

In the *Empirical Studies 3* and *4*, the methodological concept of MISTICS—a real options approach—is applied to estimate socio-economic effects from an introduction of GM HR rape seeds and GM yield-increasing wheat in Germany. Both studies conclude on positive MISTICs and by that on potential benefits to famers and the environment. Nevertheless, with the current ban of these technologies, German society passes up the potential benefits for the sake of a GM free agricultural crop production. This indicates that German society weights perceived social irreversible costs higher than perceived benefits of the technologies. It needs to be considered that the benefits, as they are determined, are mainly private (for famers) and the potential of non-private benefits (non-farmer or society) due to environmental benefits are rather low. Following GREEN et al. (2005), we suggest theoretical decompensation scenarios to transfer private to non-private benefits in the *Empirical Study 4*. In both studies, we consider reduction in carbon (C) emission as potential non-private benefits. The social costs of carbon are evaluated with € 65.18/ton of C according to TOL (2011). Other socio-economic effects in terms of, for example, food security or different other environmental impacts are beyond the scope of the analysis, since their effect is often not clearly identified and their economic evaluations are often difficult or not available in the literature. The determined MISTICs (*Empirical Studies 3* and *4*) identify an upper bound for social incremental irreversible costs (SIICs) from the introduction of an innovation, up to which the release of the new technology can be considered socio-economical. As other socio-economic effects, actual SIICs are often difficult or unfeasible to determine with our current state of knowledge, again, since they are not clearly identified and the evaluation of costs in economic units will be difficult.

The studies in the *Empirical Studies 3* and *4* take an ex-ante perspective and therefore their results depend on the assumption about future developments of costs and benefits and the adoption of the technologies. In general, the assumptions are based on empirical (ex-post) observations and results of scientific studies. The limitation of an unknown future remains and is important for the interpretation of our results. For instance, for the assumption of adoption processes, we faced the problem that neither HOSUT nor any other type of GM wheat was ever introduced to a commercial market before and GM HR rapeseed was only introduced in North America, Australia, and Chile (JAMES, 2014). Therefore, we approximated an adoption function for the *Empirical Studies 3* and *4* based on data for the adoption of hybrid rapeseeds in Germany. Even though HOSUT lines and GM HR rapeseeds differ from hybrid rapeseeds due to their breeding technology, characteristics and species, using these data enable us to estimate an adoption function for a recent yield-increasing innovation for German agricultural crop production.

Within the real option framework past volatility drives uncertainty and influences the size of the hurdle rates. Consequently, higher past volatility increases the MISTICs value. The period of 2006 to 2013, as considered to estimate future volatilities, is characterized by high volatility across agricultural commodity markets. Consideration of another time span will affect the estimation of volatility and consequently the options value and the MISTICs value.

Regulators can use the MISTICs measures to structure their decision-making process. If they want to maximize society's welfare, innovations should be immediately released if MISTICs are smaller than actual SIICs or than the society's perceived costs. However, MISTICs do not consider the distribution of private to non-private benefits, which might also influence the citizen attitudes and regulatory preferences.

In the *Empirical Studies 5*, multi-output multi-input distance functions are applied to observe interactive and substitutional economic relationships between inputs and outputs for European crop production. The empirical analysis is based on a comprehensive farm accounting data set (FADN). Specifically, we analyze the importance of seeds as a production input for wheat output for European crop farmers. Based on this a marginal shadow value (MSV) for yield-increasing wheat seeds is derived through an economic evaluation of the marginal effects between the input 'seed' and the output 'wheat'. The findings suggest that MSVs will differ for European crop farms due to general production differences in regions and economic classes. For the estimation of a shadow value for yield-increasing seeds, we are limited to marginal effects. Thus, the determination of a complete shadow value for HOSUT seeds, which showed yield-increasing potential of 28% (see *Section 3.1.1*) cannot be accomplished with this approach. Further, the MSV reflects only private, and no non-private, benefits from a yield-increasing innovations. Still, the MSV gives important information about the economic relevance of seeds as a production input.

The *Empirical Studies 3, 4,* and *5* analyze the impact of crop innovations on farm level. Within the studies It is assumed that society do not evaluate crop innovations from GM breeding differently than those from conventional breeding methods. Thus, the presence of GMOs is not assumed to affect the market price of the crop product. However, from our conclusions in the *Empirical Study 2* we are aware that market prices are likely to change with the introduction of GM crops. Nevertheless, any assumption about the extension of the prices difference due to regulatory costs, such as coexistence measures (SKEVAS et al., 2010), segregation costs and labeling (MOSCHINI and LAPAN, 2006, ZILBERMAN, 2006) would be vague. Further, in the *Empirical Studies 3, 4,* and *5*, it is assumed that switching between conventional and GM crop production is costless, including no differences in seed prices. Under *Section 3.4* we discussed that this assumption does not hold in agricultural practice. It is also important to consider that the results in the *Empirical Studies 3, 4,* and *5* are based on current European farming conditions and patterns, even though new technologies might imply further changes in the production system. Furthermore, in each case conclusions about the economic potential are drawn only for one breeding innovation for one crop, ceteris paribus. To assess the general socio-economic potential of GM crops in Europe all available GM innovations for every crop are needed to be considered.

Eventually, the issue of socio-economic evaluation of GM breeding innovations are addressed from different perspectives applying different research designs and methods. The applied approaches can also be used for socio-economic assessment of other innovations in agricultural production.

6 General Conclusion

In general, the *Empirical Studies 3, 4,* and *5* conclude that plant breeding innovations offer potential economic benefits for European crop farms. However, GM based plant breeding innovations raise also society concerns which implies regulatory challenges for political decision makers. Further, regulatory complications if unauthorized GM traits appear within the supply chain are indicated in the *Empirical Studies 1* and *2*. European countries, except Spain and Portugal, pass up potential farm and environmental benefits from GM crops for the sake of a GM free agricultural production. The general reason might be a combination of reluctant attitude towards GM crops by the society and relatively low economic potential for farmers and other stakeholders (*Section 3.4*). Notwithstanding the reasons for the observed reluctant attitude of the society, currently, the perceived costs, associated with the introduction of GM crops, are weighted higher than the potential benefits by the majority of the society. Thus, a political deadlock regarding the approval of cultivation of new GM crops is consistent.

With the conducted economic analyses, we contribute to the ongoing social and political debate by making objective observations and estimations of the potential economic benefits and socio-economic effects from GM crops. Facing global challenges, such as climate change, increasing demand for food and feed, and a dwindling natural resource base, development and adoption of agricultural innovations are critical for a future sustainable agriculture and a necessity for humankind. Conventional and GM agricultural plant breeding are keys to cope with these global challenges. Obviously, these challenges cannot be met by innovations in (GM) plant breeding alone. In terms of agricultural production various innovations in conventional and organic farming practice are necessary. For the sake of society's benefit, innovations from a conventional or organic production system might not be seen as contradictory, but rather potentially complementary. Furthermore, innovations along the supply chain, such as in post-harvest losses or food waste management, are important for a more sustainable agricultural system. With respect to climate change, different innovation objectives, such as sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing or removing greenhouse gas emissions (FAO, 2017a), are summarized under the term climate smart agriculture.

6.1 Policy implications

As pointed out in the beginning of this dissertation (S*ection 2*), no political recommendation on whether or not to ban GM crops is implied by the results of the conducted studies. Rather, the aim is to objectively analyze economic issues of exemplary GM crops. The results and conclusions of the previous empirical studies provide important information for decision makers. However, it remains their task to weigh the benefits against the potential irreversible hazards and society's perceived costs associated with an immediate deregulation of GM plant breeding innovations. It is well known that regulators and other governmental agencies in general do not follow the outcome of pure economic analyses (WESSELER, 2014). Regulatory decisions are made within a complex environment with different political interest groups, political power constellation and politicians' personal objectives. Further, especially in democratic political systems media (VIGANI and OLPER, 2014) and lobby groups (FAGERSTRÖM et al., 2012) influence political decisions as they have large impact on the society's or voter's opinions.

Despite the political situation in Europe, GM crops are rapidly adopted in other parts of the world (see *Section 3*). In 2014 181.5 million ha, an area about 1.5 times as large as the entire European crop production area (FAOSTAT, 2016), were globally cultivated with GM crops (JAMES, 2014). The EU is a major importer of GM crops and its trading policy does not necessarily inhibit global cultivation of GM crops. Thus, even if EU regulations prevent further cultivation of GM crops on EU territory the dependency, especially for protein demand for feeding livestock, will remain. Then again, EU regulations on cultivation of GM crops can be an exemplary case for developing countries (PAARLBERG, 2009) and a reason why many Africa countries do not adopt GM crops (EVENSON, 2006). However, different international studies show that the adoption of different GM crop technologies are linked to economic benefits for farmers, especially in developing countries (see S*ection 3.4.2*). It is important to consider that the majority of societies in developing countries depend on agricultural production as their source of income and food. Thus, the social relevance of these potential economic benefits is different. Further, under climatically challenging cultivation conditions, as in many developing countries, GM plant breeding of drought and salt tolerant plants can offer private (farm) benefits. Additionally, biofortified crops, such as Golden Rice (generation II GM crops), can significantly contribute to food quality and fight malnutrition in these countries (STEIN et al., 2006, WESSELER and ZILBERMAN, 2014). Due to the potential human benefits in developing countries, 107 Nobel Laureates recently signed an open letter to Greenpeace to cease its campaign against biotechnological innovations in agriculture and Golden Rice in particular. The letter also addressed governments to reject campaigns against this technologies (SUPPORT PRECISION AGRICULTURE, 2016).

GM crops remain a complex regulatory challenge under current attitudes of societies and political environments. It is important to consider that GM crops are a global issue and that the strict European regulatory standards do have global impacts. E.g. with a mechanism VOGEL (2009) labeled 'trading up', the European regulatory standards led to an upward convergence in international regulatory standards of GM crops. Wealthy European countries set high regulatory standards for food and foreign suppliers that want to serve the European market must produce the appropriate products (PAARLBERG, 2009). Policy makers in developed countries need to be aware of this and other impacts of their decisions on developing countries.

6.2 Outlook for further research

On the one hand, GM plant breeding innovations offer potential to reduce poverty and to contribute to food stability and food security, especially in developing countries (see *Section 3.4*). On the other hand, plant breeding innovations based on GM technology cause various concerns in society. Therefore, their analysis in different scientific fields and with different approaches is necessary to find the most efficient ways of regulatory handling of each technology.

GM plant breeding innovations will have economic effects for seed developer, farm production, the environment, consumers and markets and can be a study objective for plant and environmental science, economics and sociology. The interdisciplinary connection of different scientific fields will be important to optimize recommendations for political decision making.

Plant breeding will face an uphill task to find creative solutions and develop innovative traits and varieties for various agricultural and social challenges. New varieties need to be tested in field trails under different farming patterns and conditions not only for their farm-level potential but also for their environmental impact. In addition, motivated by social concerns about irreversible cost or potential long term downsides, a pronounced biosafety risk assessment of GM crop products will be needed. Eventually, different breeding approaches and their field studies will extent the knowledge about their risks and about the different ecological relationships. Thus, over time more information from practical applications, field studies and risk assessments will decrease uncertainty and improve the quality of socio-economic assessment of GM plant breeding innovations.

An economic evaluation of a breeding innovation can be straight forward in terms of yield increase and savings in production costs. But the economic evaluation of some effects remains difficult, even if an effect is clearly identified, such as the impact of occurring resistances or the environmental impact. Future research faces the challenge to weight such effects economically while considering different regions, farming practices, and crop types. Further, plant breeding innovations might be directly linked to farm income and the health status of member of the farm household. Such effect and their linkage to poverty reduction are especially important for developing countries. Especially in these countries, consumers potentially benefit from plant breeding innovations in terms of food stability and food safety. A challenge for future research will be to determine the size of the effects and to weight them economically. The methodical framework of *Disability Adjusted Life Years (DALYs)*, as applied by WESSELER and ZILBERMAN (2014) for Golden Rice, offers a standardized approach to account for potential consumers' benefits, especially in developing countries. With a further development of generation II GM crops that framework, or similar approaches, might be used in future studies.

Besides the determination of the size and relationships of economic effects, it is also important to analyze how benefits and costs are distributed between research companies, farms, the environment and consumers. Regulative approaches should be developed to avoid that benefits are primarily captured by private companies.

The political decision about deregulation of cultivation strongly depends on consumer acceptance of the technology. Thus, development of the consumer attitudes will be decisive for the future of cultivation of GM crops. It will be important to analyze the forces which affect consumer attitudes towards plant breeding innovations. At this, the motivation and impact of political interest groups or lobbies must be considered. Furthermore, the observation and analyses of future consumer attitudes towards new breeding innovations is important. In this context, different developments are possible. In one scenario, new breeding techniques, such as CRISPR/Cas9, will experience wider society acceptance in the future. The negatively associated term 'Genetic Modified Organism' might not be used for these techniques and the regulatory challenge might change. In another scenario, consumer acceptance of GM crops might increase due to benefits associated with next generation GM crops. Of course, also the possibility of remaining reluctant consumer attitudes exists. Studies about consumer's willingness to pay or accept for different innovations and region can help to observe this development.

The analyses in the *Empirical Studies 3, 4,* and *5* assume no price or trading differences for GM and non-GM crops. Future studies which follow similar research designs could improve the assumption and integrated a market model. However, such a model needs to include varies aspects, such as adoption of innovations, substitutability of crops, increasing world population, changing food consumption as well as trade issues including consumer preferences and segregation costs for GM and non-GM crops.

Further research aspects associated with GM crops include the social effect of price changes in different regions, the development of market concentration within the seed sector (discussed in *Section 3.4*) and its consequences for innovations development and the distribution of innovation's benefits.

The future research areas mentioned above should help to deepen the understanding of global GM crop development and to understand the EU with only very little cultivation of GM crops. A central aim for future research should be policy recommendations about regulation decision of plant breeding innovations. Such a recommendation should be based on extensive analyses about potential effects on famers, the environment, and consumers.

7 Publications and authors contribution

Empirical Study 1

Wree, P. and J. Wesseler (2016). Consequences of Adventitious Presence of Non-approved GMOS in Seeds: The Case of Maize Seeds in Germany. *The Coexistence of Genetically Modified, Organic and Conventional Foods*. Springer, 177-183.

Author contributions: JW contributed with the Idea for the case study. PW put together the historic facts and mainly drafted the manuscript. All authors contributed to structure the study.

Empirical Study 2

Wree, P. and H. Gerhard (2015). The impact pf GMO appearance on the global wheat market. In, *54th Annual Conference, Göttingen, Germany, September 17-19, 2014*. German Association of Agricultural Economists (GEWISOLA).

All authors contributed to the general research design and conduction of the analysis. GH mainly collected the data. PW drafted the manuscript and communicated the research.

Empirical Study 3

Wree, P. and J. Sauer (2016). Genetically Modified Herbicide Resistant Rapeseed in Germany: A Socio-Economic Assessment. *German Journal of Agricultural Economic,* 65(4): 244-253.

All authors contributed to the general research design. PW conducted the data collection together with Peter Liebhardt (student research assistant). PW conducted the analysis and drafted the manuscripts.

Empirical Study 4

Wree, P. and J. Sauer (2017). High-Yielding Genetically Modified Wheat in Germany: Socio Economic Assessment of its Potentia. *Agricultural Economics Review* 17(1): 80.

All authors contributed to the general research design. PW conducted the data collection together with Gerhard Heinrich (student research assistant). PW conducted the analysis and drafted the manuscripts.

Empirical Study 5

Wree, P. and J. Sauer (forthcoming): Economic Evaluation of Yield-increasing Wheat Seeds Using a Distance Function Approach

JS contributed with the general research question. All authors developed the research design. All authors applied for the used FADN data set. PW conducted the analysis and prepared the first paper draft. JS provided advice on the development of the paper as well as editorial input.

8 Summary of Publications

In the following, summaries of the *Empirical Studies 1, 2, 3, 4,* and *5* are given.

8.1 Summary of Empirical Study 1

Consequences of Adventitious Presence of Non-approved GMOS in Seeds: The Case of Maize Seeds in Germany

In the EU genetically modified (GM) events, not approved for cultivation, have a zero tolerance in commercial seeds or propagation material (BUNDESVERWALTUNGSGERICHT, 2012). The case study in *Empirical Study 1* introduces two cases of adventitious presence of unapproved GM events in European crop production. In 2010 the BASF GM potato variety Amadea appeared in propagation fields of the BASF GM potato variety Amflora in Sweden. Amflora was a variety approved for commercial cultivation in the EU but, Amadea was only authorized for research cultivation. Even though the rate of admixture in the field was under 0.01%, the entire harvest was destroyed (BASF PLANT SCIENCE, 2010). Since the adventious presence of unapproved GM events was detected early and the harvest not further distributed, the situation did not cause severe regulatory challenges. In another case, also in 2010, seed samples of the maize variety PR38H20 from Pioneer, dedicated for the German market, tested positive for the Monsanto GM event NK603. Varieties including this event are not approved for cultivation by the EU. Unfortunately, by the time the positive test results were announced, relevant maize seeds had been already sold to farmers, and 229 of them had sown those seeds on a total area of 1650 hectares. These farmers were requested by their federal ministries to destroy their maize crops which was possibly cultivated with GM seeds. The decree did not include any guarantee of financial compensation. After negotiations with the federal state of Lower Saxony, which detected the adventious presence of GM events in their tests, and the famers' interest group Deutscher Bauernverband, Pioneer offered an immediate compensation payment of € 1800 per hectare to the affected farmers. In November 2010, Pioneer announced that 228 of 229 affected farmers had accepted their offer (AGRARHEUTE, 2010). After the settlement with the farmers, different law cases were filed to clarify legal responsibilities in the general case of appearance of unapproved GM events in seed.

We diligently compile the facts of the above case and point out regulatory challenges, legal insecurities and the necessity for communication improvements among the different stakeholders involved. The preparation of the case study required extensive information research including literature research as well as communication with experts of the seed industry and the affected stakeholders.

8.2 Summary of Empirical Study 2

The Impact of GMO appearance on the global wheat market

For different reasons, mainly concerning consumer preferences (BERWALD, 2006), wheat is the only major crops without any GM products on the market. Still, on 05.05.2013 the Oregon State University informed the United States Department of Agriculture (USDA) that wheat samples from Oregon were tested positive for glyphosate resistance introduced by GM technology. 24 days later the USDA confirmed these test results. Thereafter, the Japanese government immediately halted wheat imports of Soft White Wheat (SWW) and Wheat White (WW), which are produced in the Oregon area and to a large extent exported to Asia. Two days later, the Republic of Korea also stopped part of their U.S wheat imports and the EU advised their member states to intensify testing for traces of genetically modification organisms (GMOs) in U.S. wheat imports. The import ban was lifted after 41 trading days. It was the first time that GM events caused international trading turbulences in the wheat market. To analyze the impact of the temporary import ban we employ periodic cointegration analysis on time series of the Portland spot price (Portland, Oregon, is the most important export location for wheat from the U.S. to Asia) and nearby futures prices from America, Europe, and Australia. We perform varies cointegration test in different groups and pairs. With the applied research design, we investigate if price formation on global wheat markets changed fundamentally during the time of the ban.

Our findings indicate that most global wheat prices are cointegrated before the import ban, which supports the assumption of the law of one price (LOP) even though wheat can be seen as a heterogeneous good due to its origin and physical characteristics. However, during the time of the import ban common cointegration relationships between different wheat prices disappeared. In our view, the changed price formation illustrates the effect appearance of non-approved GM wheat within trading regulations restricting GMOs. Conclusively, a relatively small ban, restricted to specific types of wheat (SWW and WW) and origin (Oregon), led to general disturbances on the global wheat market indicating limited economic potential of GM wheat.

The research framework based on cointegration analysis is especially motivated by and designed for the specific research question. In addition, the data set was specifically constructed for the purpose of this study.

8.3 Summary of Empirical Study 3

Genetically Modified Herbicide-Resistant Rapeseed in Germany: A Socio-Economic assessment

Genetically modified (GM) herbicide-resistance (HR) rapeseed varieties are cultivated in Canada, the U.S., Australia, and Chile and account for approximately 25% of the global annual rapeseed production (James, 2014). European Farmers cannot experience possible benefits from cultivating GM HR rapeseeds, as currently none such variety is approved for cultivation in the European Union. In an economic interpretation of the situation, European decision makers evaluate possible irreversible costs of the technology as too significant compared with its potential benefits.

In order to give more objectively structured information behind this decision making process we analyze the socio-economic potential of an immediate release of GM HR rapeseeds by considering private and social reversible and irreversible costs and benefits. Similar to *Empirical Study 4* we determine, ex-ante, maximum incremental social tolerable irreversible costs (MISTICs), a methodological approach based on real options theory. MISTICs identify an upper bound for social incremental irreversible costs from the introduction of an innovation, up to which the release of the new technology can be considered socio-economically justified.

For the period 2007-2013 we composed time series for gross margins and environmental impacts per hectare for conventional and HR rapeseed cultivation. On average the net incremental reversible private benefits of GM HR rapeseeds are estimated to be € 242.58/ha/a. As environmental impact we consider reduction of CO_2 equivalent under low tillage cultivation, as facilitated by HR varieties, compared to convention production systems. The differences of the systems is on average 160.89 kg CO_2 equivalent/ha/a. We evaluate the CO_2 equivalent with € 65.18/tonne of carbon following the literature review on social evaluation of carbon by TOL (2011).

The derived MISTICs indicate that banning GM HR rapeseeds is only appropriate if German society values the possible total accumulated irreversible costs of this technology (from its introduction until infinity) with at least € 1.105 billion in total or € 13.8 per citizen. Besides MISTICs we determine an option value of € 249.058 million, which can be interpreted as the monetary value for the possibility of introducing GM HR rapeseed cultivation at some point in time. Both results indicate potential benefits to famers and the environment. Nevertheless, with the current ban of GM HR rapeseeds, German society elects to pass up the potential benefits for the sake of crop production free of genetically modified organisms.

8.4 Summary of Empirical Study 4

High-Yielding Genetically Modified Wheat in Germany: Socio Economic Assessment of its Potential

Researchers at the publically funded IPK (LEIBNIZ-INSTITUT FÜR PFLANZENGENETIK UND KULTURPFLANZENFORSCHUNG) in Gatersleben, Germany, used genetic modification (GM) technology to develop winter wheat lines with high yield potential named HOSUT. In trails for the new lines, grain yield significantly increased by 28% on average when compared to the non-GM control line (SAALBACH et al., 2014).

The discovered yield increasing mechanism could significantly contribute to a sustainable increasing global wheat production. In this study we conduct an economic impact assessment can help to structure the political decision about the support of research and development of the GM based innovation. We apply the real options concept of Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) to conduct an ex-ante assessment of the potential economic impact of HOSUT wheat for Germany. MISTICs identify an upper bound for social incremental irreversible costs from the introduction of an innovation, up to which the release of the new technology can be considered socio-economically justified. The MISTICs model is similar to the one in *Empirical Study 3* and considers private and social reversible and irreversible costs and benefits. However, we design different scenarios, which account for potential effects for wheat farmers and society if the introduction of the HOSUT technology is combined with decompensation areas as a political condition. With the decompensation scenarios, the innovation has not just private but also environmental or social benefits. For our model we make assumptions based on SAALBACH et al. (2014) and combine these with findings about the wheat production system in Germany. We construct data sets for the period 2006-2013 to compare private gross margins and environmental effects of conventional and HOSUT wheat. We consider saved CO_2 equivalent emissions due to decompensation zones as environmental impact. The CO_2 equivalent is evaluated at € 65.18/tonne of carbon following the literature review on social evaluation of carbon by TOL (2011).

Our results indicate that not authorizing HOSUT wheat is correct if German society values the hazard of social irreversible costs from this GM wheat to be between € 7.75, in a decompensation scenario and € 12.78, under a regular production system. The theoretical concept of decompensation areas indicates potential non-private or environmental benefits from yield increasing seed innovations. Despite these potential benefits, the introduction of GM wheat lines into the European Union or

German market seems to be very unlikely under the current social and political rejection towards genetically modified organisms.

8.5 Summary of Empirical Study 5

Economic Evaluation of Yield-increasing Wheat Seeds Using a Distance Function Approach

Wheat is one of the most important crops for global food security (Shiferaw, et al., 2013) and yield-increasing breeding innovations are crucial to keeping up with increasing global demand. In addition to social relevance in terms of food security, wheat is also the most important crop for European farmers. Wheat is cultivated on approximately 26% of the 100.3 million ha of arable land in the EU-28 (FAOSTAT, 2016).

In *Empirical Study 5* stochastic frontier analysis is used to construct multi-output multi-input distance functions to observe economic relationships between inputs and outputs of European crop production technologies. The estimated functions provide empirical applications for measuring farm efficiency and productivity (Zhou, et al., 2014) and account for complementarity and supplementarity of inputs (Sauer and Wossink, 2013). We determine the production characteristics: technical efficiency (TE), technical change (TC), and scale elasticity (SE). Additionally, we exploit the duality between distance functions and cost functions and derive marginal shadow value (MSV) through an economic evaluation of the marginal effects between the input ‘seeds’ and the output ‘wheat’. With the MSV we evaluate the economic impact of marginal yield-increasing innovations in wheat seeds for European crop farmers. The MSV measures the economically justified costs for seeds that marginally increase yields, or outputs, in wheat production under the assumption of optimal input combination. The conceptual framework is applied to a comprehensive unbalanced panel of European Farm Accounting Data (FADN data) from 23 European countries for the period from 2005 to 2012. The FADN data set consists of annual accountancy data from a sample of commercial agricultural holdings in the EU. Access to FADN data requires an application process including the presentation of an appropriate and convincing research design and a concept for responsible data handling. The designed data set includes 73,719 observations which focuses on specialized crop farms. The results of the analysis of European specialized crop farms show on average TE of 0.912, TC of −0.291% and SE of 0.520. The MSV for marginal yield-increasing wheat seeds corresponds to 18.87 €/ha on average. However, farm individual shadow values will differ from that due to general differences in regions, economic classes and SE. The results of the study are independent of any breeding techniques such as conventional, hybrid and GM and only consider private economic farm level effects.

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Appendix

Appendix 1: Poster *Empirical Study 2*

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THE IMPACT OF GMO APPERANCE ON THE GLOBAL WHEAT MARKET

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The Story:
On 05.05.2013 the Oregon State University informed the United States Department of Agriculture (USDA) that wheat samples from Oregon were tested positive for glyphosate resistance caused by GMO technology. On 29.05.2013 the USDA confirmed the testing results. The Japanese government immediately halted wheat imports of Soft White Wheat (SWW) and Wheat White (WW), which are produced in the Oregon area and to a large extent exported to Asia. Two days later, the Republic of Korea also stopped parts of their U.S wheat imports. After one month, Japan and the Republic of Korea returned to buying SWW and WW.

Source: http://www.getholistichealth.com/wp-content/uploads/2013/08/South-Korea-joins-Japanese-ban-on-U.S.-wheat-imports-after-shocking-GMO-contamination-announcement-by-USDA.jpg

Source: http://www.hartmann-reederei.de/fleetlist-linkage.php?lang=de&fleet=bulkcarrier&linkage=SupramaxBulki

The Question: Are global wheat prices cointegrated and did the ban by Japan and the Republic of Korea changed the cointegration relationship?

Data: Five wheat prices time series (WPTS):
wheat spot price from Portland, nearby wheat futures prices from CBOT, KCBT, MGEX, MATIF, ASX (USDA, 2014; HGCA, 2013)

Four time ranges:
A (01.08.2006 - 17.01.2014): Long term
B (03.04.2013 - 29.05.2013): Before the ban
C (05.06.2013 - 31.07.2013): During the ban
D (05.06.2013 - 31.07.2013) : After the ban

The Method:
- Periodic cointegration analysis to characterize the relationship between the different WPTS in different time ranges (A, B, C, D)
  → non stationary time series are cointegrated if a linear stationary combination of the time series exists (Engle & Granger, 1987)

Step I:
- Test for stationarity in levels and first difference
  → the results indicate stationarity in I(1). Thus, we can continue with Step II

Step II
- We perform pairwise Johansen cointegration test to test whether the WPTS have a cointegration relationship in different periods or not

Test for stationarity Time range: A, B, C, D
With constant and trend

	Time range: A		Time range: B		Time range: C		Time range: D	
	ADF		KPSS		PP		ADF	
	Levels	First difference	Levels	First difference	Levels	First difference	Levels	First difference
ASX	-2.4311	-34.0487**	0.1193*	0.0820	-2.4712	-16.6413**	-2.5930	-5.9633**
CBOT	-2.6368	-16.9142**	0.0484**	0.0748	-2.4369	-4.0574**	-1.3573	-9.8413**
KCBT	-2.1753	-44.7552**	0.1483**	0.0372	-2.4634	-4.0764**	-2.6192	-7.5693**
MATIF	-1.8754	-16.5248**	0.1484**	0.0949	-2.8287	-5.7247**	-2.8430	-7.5739**
MGEX	-1.8549	-16.7509**	0.1590**	0.1085	-2.3540	-5.2989**	-3.2476	-3.4978**
Portl.	-2.4945	-9.8017**	0.1989**	0.0623	-2.3279	-4.5953**	-1.2343	-8.2910**

Note: The optimal lags for the ADF (Augmented Dickey-Fuller) test were selected based on optimizing Akaike's Information Criteria (AIC), using a range of lags. The bandwith for PP (Phillis-Perron) and KPSS (Kwiatkowski-Phillips-Schmidt-Shin) are selected using the Newey-West method.
** and * denote rejection of the null hypothesis of unit roots/ non-stationarity for ADF and PP at the 5 percent and 10 percent significance levels, respectively.
** and * denote rejection of the null hypothesis of no unit roots/ stationarity for KPPS at the 5 percent and 10 percent significance levels, respectively.
For ADF and PP the critical values at the 5 percent and 10 percent significance levels are -3.4121 and -3.1280, respectively. The critical values are based on McKinnon (1996)
For KPSS the critical values at the 5 percent and 10 percent significance levels are 0.146 and 0.119, respectively.
The critical values are based on Kwiatkowski-Phillips-Schmidt-Shinn (1992)
All tests are performed assuming the data have an intercept and a trend.

Time range A

Trace statistic COIN A with restricted constant

	CBOT		KCBT		MATIF		MGEX		Portl.	
ASX	$r = 0^*$	26.248	$r = 0^*$	20.536	$r = 0^*$	30.283	$r = 0$	15.670	$r = 0^*$	26.059
	$r \leq 1$	6.5180	$r \leq 1$	4.8069	$r \leq 1$	4.6176	$r \leq 1$	4.2997	$r \leq 1$	4.8201
CBOT			$r = 0^*$	37.5718	$r = 0^*$	20.9531	$r = 0^*$	22.8171	$r = 0^*$	26.9687
			$r \leq 1$	8.1026	$r \leq 1$	4.1213	$r \leq 1$	5.5600	$r \leq 1$	4.7924
KCBT					$r = 0^*$	24.4446	$r = 0$	19.0547	$r = 0$	19.1823
					$r \leq 1$	5.1158	$r \leq 1$	4.3011	$r \leq 1$	4.9533
MATIF							$r = 0^*$	20.4357	$r = 0^*$	21.5140
							$r \leq 1$	5.5197	$r \leq 1$	4.2116
MGEX									$r = 0^*$	28.3673
									$r \leq 1$	6.3223

* denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999)

Time range B

Trace statistic COIN B with restricted constant

	CBOT		KCBT		MATIF		MGEX		Portl.	
ASX	$r = 0^*$	21.0159	$r = 0^*$	21.2994	$r = 0$	18.8520	$r = 0^*$	27.4522	$r = 0^*$	21.3217
	$r \leq 1$	7.1114	$r \leq 1$	3.8567	$r \leq 1$	1.8235	$r \leq 1$	3.4290	$r \leq 1$	8.9058
CBOT			$r = 0^*$	21.9222	$r = 0^*$	22.1854	$r = 0^*$	23.4821	$r = 0^*$	30.6083
			$r \leq 1$	1.4391	$r \leq 1$	1.3300	$r \leq 1$	2.9545	$r \leq 1$	7.0045
KCBT					$r = 0$	7.1108	$r = 0$	11.3797	$r = 0^*$	20.888
					$r \leq 1$	1.3395	$r \leq 1$	3.0746	$r \leq 1$	3.6610
MATIF							$r = 0$	9.5874	$r = 0$	19.6148
							$r \leq 1$	1.9352	$r \leq 1$	4.5290
MGEX									$r = 0^*$	26.146
									$r \leq 1$	8.6145

* denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999)

Time range C

Trace statistic COIN C with restricted constant

	CBOT		KCBT		MATIF		MGEX		Portl.	
ASX	$r = 0$	15.3158	$r = 0$	16.6678	$r = 0$	14.3118	$r = 0$	10.9577	$r = 0$	15.4034
	$r \leq 1$	5.7235	$r \leq 1$	7.1332	$r \leq 1$	4.8220	$r \leq 1$	3.2181	$r \leq 1$	4.9388
CBOT			$r = 0$	11.0566	$r = 0$	17.1504	$r = 0$	12.9727	$r = 0$	19.5560
			$r \leq 1$	1.0102	$r \leq 1$	5.0743	$r \leq 1$	2.5042	$r \leq 1$	7.4826
KCBT					$r = 0$	12.6453	$r = 0$	9.1155	$r = 0$	15.7990
					$r \leq 1$	3.1335	$r \leq 1$	0.9063	$r \leq 1$	6.6427
MATIF							$r = 0$	14.6961	$r = 0$	13.5362
							$r \leq 1$	2.6654	$r \leq 1$	5.5234
MGEX									$r = 0$	8.7772
									$r \leq 1$	2.6475

* denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999)

Time range D

Trace statistic COIN D with restricted constant

	CBOT		KCBT		MATIF		MGEX		Portl.	
ASX	$r = 0$	18.0562	$r = 0$	14.0241	$r = 0$	16.5967	$r = 0$	12.7823	$r = 0^*$	23.6616
	$r \leq 1$	3.3778	$r \leq 1$	2.2921	$r \leq 1$	3.7534	$r \leq 1$	3.3687	$r \leq 1$	4.2905
CBOT			$r = 0$	16.1831	$r = 0$	13.5609	$r = 0$	14.1559	$r = 0$	11.0597
			$r \leq 1$	6.9802	$r \leq 1$	5.3101	$r \leq 1$	2.4291	$r \leq 1$	0.8445
KCBT					$r = 0$	13.0421	$r = 0$	10.0209	$r = 0$	7.5965
					$r \leq 1$	4.4936	$r \leq 1$	2.8292	$r \leq 1$	1.1769
MATIF							$r = 0$	10.7173	$r = 0$	8.6478
							$r \leq 1$	2.9180	$r \leq 1$	2.0507
MGEX									$r = 0$	9.7724
									$r \leq 1$	3.9338

* denote rejection of the null hypothesis of no cointegration at the 5 percent significance levels.
The critical value (at the 5 percent significance levels) for $r = 0$ and $r \leq 1$ are 20.262 and 9.165, respectively.
Critical values are based on MacKinnon-Haug-Michelis (1999)

The conclusion:
In the long run (time range A) global wheat prices are cointegrated in 12 out of 15 cases → points to a global cointegrated wheat market and LOP.

In the short run cointegration relationships are less pronounced.
Still, before the ban 10 out of 15 price pairs are cointegrated. The CBOT nearby futures is cointegrated with every other wheat price → shows the importance of the CBOT for global wheat price determination

During the ban (time range C) non of the price pairs have been cointegrated → together with the import ban global wheat price relationships changes

After the ban (time range D) only one cointegration relationships occurred → the effect of the ban continued or prices return to their general relationship

The ban on the GMO contaminated wheat variety came along with general distortions of the wheat market

Sources: USDA. (2014). Agricultural Marketing Serivce from United States Departmend of Agriculture http://search.ams.usda.gov/mnsearch/mnsearch.aspx
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Appendix 2: Poster *Empirical Study 4*

A SOCIO ECONOMIC ASSESSMENT OF YIELD INCREASING GM WHEAT IN GERMANY

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Agricultural Production and Resource Economics

Introduction/ Objectives

- 20% of the world's calorie and protein demand is met by wheat (Shiferaw et al., 2013) By that wheat is the most important source for carbohydrate in human nutrition and is crucial for food security
- German wheat breeders have used GM technology to develop novel winter wheat lines named HOSUT. In field trails HOSUT lines showed a yield increase potential of 28% (Saalbach et al., 2014).
- Ex-ante we analyze the socio-economic potential of an immediate market introduction of HOSUT wheat in Germany and determine Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) (Wesseler, Scatasta, & Nillesen, 2007)
- A scenario with decompensation indicates the social benefit potential

Material and Method

Incremental benefits and costs of the HOSUT innovation are distinguished with respect to reversible and irreversible private, non-private and social. The different scenarios show the incremental effect of the cultivation of HOSUT lines compared to their conventional counterpart. Additional to the assumption under scenario I, scenario II includes a decompensation zone, within the area dedicated to wheat cultivation, just as large that the absolute crop yield per hectare remains constant.

			Private (farmer) aspects	Non-private (non-farmer) aspects	Social	Symbols
Scenario I	Benefits/ ha	Incremental irreversible	Irrelevant	Irrelevant	∑(private + non-private) aspects	J
		Incremental reversible	Higher yield (28%)	Irrelevant		W (net benefits)
	Costs/ha	Incremental reversible	Lower price for less quality (lower protein content); higher absolute handling costs	Irrelevant		
		Incremental irreversible	Irrelevant	Possible negative effects for society		I
Scenario II With decompen-sation zone	Benefits/ ha	Incremental irreversible	Irrelevant	Input reduction due to decompensation	∑(private + non-private) aspects	J
		Incremental reversible	Less cultivation costs	Irrelevant		W (net benefits)
	Costs/ha	Incremental reversible	Lower price for less quality (lower protein content); higher absolute handling costs	Irrelevant		
		Incremental irreversible	Irrelevant	Possible negative effects for society		I

The MISTICs concept is based on the real option approach (Dixit & Pindyck, 1994) and assumes that future gross margins develop according to a Geometric Browian Motion ($dW = \alpha W dt + \sigma W dz; dz = \varepsilon_t \sqrt{dt}, \varepsilon_t \approx N(0,1)$)

Dixit & Pindyck's (1994) formulation of minimum incremental net benefits as

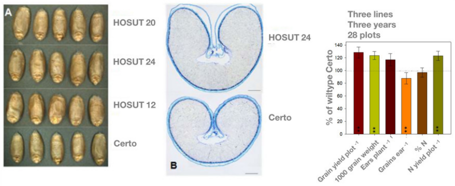
$$W^* = \frac{\beta}{(\beta - 1)}(I - J)$$

, which can be rearranged for MISTICs (I^*) as

$$I^* = \frac{\beta - 1}{\beta} W + J$$

With $\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1$ and $\delta = \mu - \alpha$

β captures flexibility, irreversibility and uncertainty with r (riskless rate of return), δ (convenience yield), μ (risk adjusted rate of return) and α (drift rate of the mean annual rate of return).



Source: Saalbach (2014)

Data

- Detailed gross margins times series per ha for German wheat farmers, considering 28% incremental yield/ha and 5% lower price due to lower protein concentration for HOSUT innovation (Saalbach et al., 2014)
- Adoption structure of the HOSUT lines is assumed to be the same as for hybrid rape seeds in Germany
- Carbon emission (tones per ha) are determined using the ENZO2 Greenhouse Gas Calculator (ifeu, 2014)
- Carbon emission are economical evaluated following Toll (2011)

Results

	$W = \int_T^\infty w_i(t) e^{-\mu t} dt$ in €	$J = \int_T^\infty j_i(t) e^{-\mu t} dt$ in €
Scenario I	1 664 140 093	-16 747 414
Scenario II	962 117 686	32 709 792

	Hurdle rate $\left(\frac{\beta}{(\beta-1)}\right)$
Scenario I	1.94
Scenario II	1.08

MISTICs (I^*) in €	Society	Per citizen	Per ha wheat (wheat cultivation in every second year)
Scenario I	840 585 436	10.44	654.72
Scenario II	926 530 829	11.51	749.12

An immediate introduction of HOSUT lines in Germany in 2014 would have been economical if the actual social irreversible costs (I) did not exceed the particular MISTICs value.

Conclusion

- When a new technology is developed for practical agricultural application decision makers have the option to postpone their decision or authorize its market introduction

  → Only if the benefit of an immediate release outweighs those of keeping the option and postponing the decision, should the option to release be exercised. MISTICs can be used for a monetary evaluation of the situation and to structure the decision finding process.

- The quite low MISTICs for German citizen (between € 11.51 and € 10.44) in combination with their negative attitude towards GMO (European Commission, 2010) indicates conflicts of interest and a low political chance for an approval of HOSUT lines anytime soon.
- HOSUT wheat might have further global potential to increasing global supply with its positive effect on price stability and food security.

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Danksagung